Learning Science with ICT -
Developing a Pedagogy of Successful Practice

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Learning science with ICT – Developing a pedagogy of successful practice

Introduction

The oeuvre which I present spans a period of time during which the use of ICT in science education has been transformed from a technical teaching aid into a major genre of activity on a national and international scale. My contribution to this change has been as a researcher, teacher trainer, software author and electronics designer. Such a combination of roles has made my approach multidisciplinary, creating a unique partnership between research, pedagogy and technical development. The fruits of my work have influenced practice directly in science departments in secondary schools through the publication of articles, chapters and a book, and especially through the dissemination of original curriculum materials, hardware tools and the *Insight* suite of software. Embedded in these tools are my understandings of the new context for learning science, rooted in constructivism and derived from professional experience, classroom research studies and research literature. My aim throughout has been to promote ideas which will help the science education community gain a vision of the full potential of ICT.

It will be shown that my activities in each of three strands, research, literature study and curriculum development, have been interconnected at many stages such that advances in one strand have prompted progress in another in a stepwise fashion. Thus, my curriculum developments have provided the tools for study, my evaluative field research has provided insights for refining the tools and of new opportunities for their use, research literature has deepened my understanding of the issues and has identified criteria for the design of the curriculum tools and for research methodology. In total, this process itself has exemplified a constructivist development and is reflected in the portfolio items which begin with practitioner articles and graduate to papers linking research findings to theoretical arguments.
**From reflective professional practice to theoretical discourse/hypotheses**

After sceptical beginnings with computers, initially using punched cards and later using teletype terminals, it was the advent of the microcomputer which initiated my vision of the educational potential of computers. I recognised that the visual possibilities of computer graphics, combined with the calculating power of computer processing, signalled a graphing capability which offered many advantages over manual paper-based methods. The appearance of the BBC Microcomputer, offering a vast improvement in the resolution of screen graphics in a variety of colours, sharpened this vision of a dynamic tool for graphical analysis. The research literature on pupils’ misconceptions with graphs (e.g. Taylor & Swatton, 1990) confirmed my view that the microcomputer promised to be a tool which could make a significant contribution to science education. The promise was based on the semi-automation of the graphing process, the enormous variety and flexibility of plotting formats and the range of software aids for analysing the graphs. These qualities could help overcome the limitations of individual pupils’ plotting skills inherent in conventional manual methods with pencil and paper.

The greatest obstacle in the plotting process was the time needed to enter the data into the computer from the keyboard. However, the arrival of the BBC Microcomputer uniquely solved the problem in the case of experimental data by permitting the connection of sensors enabling the direct measurement of a variety of physical measurements. My earliest experiments with this idea involved connecting thermistors to measure temperature, light dependent resistors to measure light intensity, potentiometers to measure angle and a number of direct voltage measurements in simple circuits with resistors, bulbs and capacitors. The connection of these components to the computer required additional circuits, external to the computer to facilitate safe connection. My work with these culminated in the design of a range of interface circuits and demonstration software and became the subject of a number of in-service training events I organised for local teachers in 1985.

Although my intention was to offer teachers ideas they might put into practice themselves, many teachers, lacking appropriate skill, requested fully developed software solutions and this launched me into the process of designing software for practical science and publishing worksheets for suitable experiments (Portfolio items 1 and 2). It also introduced me to the special discipline of designing software for the use of other teachers.
and pupils with whom I would never have direct contact. The standard demanded was
much higher than software designed for personal use and required endless trialling and
response to feedback from teachers and pupils. This practical discovery not only
established a routine pattern for future developments, it signalled recurring themes in my
research: my growing awareness of the variety of teaching styles amongst teachers, the
consequent need to maintain a pedagogical dialogue and the significance of the context of
use of ICT.

**Portfolio items:**
1. ‘Microelectronics and physical measurement’ – Leicester University (1985)
2. ‘Interfacing programs’ – Leicester University (1986)

From the outset of these developments my vision was for new methods of measurement,
new practical experiments, new ways of investigating data and new revelations about
physical phenomena in ordinary school laboratories. In the article ‘The computer-assisted
laboratory’ (Portfolio item 3) I described how a range of skills and activities associated
with practical laboratory work might be enhanced by the use of the new technology.

**Portfolio item3:**
‘The computer-assisted laboratory’ - Physics Education 22 (1987) 219-224

My trials of IT activities with pupils led me to believe that such activities could facilitate
better understanding of the science phenomena involved and ultimately better learning. A
good example of this promise emerged from my development of the motion sensor
hardware and software (Appendix B). My experiments with this demonstrated that 12
and 13 year old pupils were able to talk intelligently about velocity and acceleration from
the novel experience of observing graphs of their motion on the computer screen as they
walked backwards and forwards in front of the sensor (Portfolio item 4). My paper ‘The
computer as an aid to practical science - studying motion with a computer’ proposes and
describes a range of novel investigations for pupils with the motion sensor and light gate
(Portfolio item 5).

**Portfolio items:**
4. ‘A surprising sensor’ Micromath (Summer 1989) Vol.5 no.3, 41-43

At the time, this investigative style of pupil activity was being newly promoted in the National Curriculum (Attainment Target ‘Exploration of Science’) and in my paper ‘IT in science in the National Curriculum’ (Portfolio item 6), I argued that a broad range of different types of IT application fulfilled this curricular ambition.

**Portfolio item 6:**


At this stage, many of my ideas about the learning potential were borne out of professional experience as a school teacher and trialling activities with pupils, but as my research studies progressed, I found support and further refinement from the research literature. focussing initially on graphing skills (for example, Phillips, 1986) and later on the constructivist basis for an investigative style of learning (for example, Driver et al, 1994). However, as will be explained later, in the particular field of data-logging, the contemporary active development of hardware and software tools meant that published research usually lagged behind current potential. In this context, the need for my own classroom-based studies became increasingly important.

**Identifying and understanding the benefits of ICT**

By the early 1990s, data-logging hardware, software and curriculum ideas were well established, although take up in schools was very patchy and largely dependent on local enterprise. In such a climate, most developments had been mainly shaped by the professional insights and experience of enthusiasts for the technology rather than being driven by considerations of learning theories. As a result, developments nationally embraced a great diversity of practice and values amongst teachers and developers and, although there emerged a general professional belief that data-logging, along with IT in general, was a beneficial innovation, there was no clear consensus about the specific nature of supposed benefits. The ImpacT study (Watson, 1993) indicated that ICT could raise pupils’ motivation, and focus their attention for long periods, resulting in raised
quality of work. It could also foster collaborative work which has long had an important role in science practical. The labour saving aspects of ICT could be recognised, but the extent to which these contributed to improved learning was difficult to quantify. Kemmis et al (1977) distinguished between pupils' authentic labour (that which is valued as learning) and inauthentic labour (that which contributes to learning but is not valued in its own right) and proposed that ICT had the potential to reduce the latter. However, sometimes the uncritical use of computer power might replace a skill whose acquisition serves a valued learning purpose (Scaife & Wellington, 1993). A further difficulty was that often ICT did not offer a simple alternative to conventional practice, it actually changed practice, so that comparisons between old and new methods were invalid (Hammond, 1994).

The latter arguments have been especially relevant to graphing skills in that data-logging software can display data on a graph simultaneously with the collection of the data in an experiment; the manual skill of plotting a graph appears to be displaced by the new opportunity of associating the graph shape directly with the phenomenon under investigation. In my paper 'A Study of Pupils’ Skills of Graphical Interpretation with Reference to the Use of Data-Logging Techniques' (Portfolio item 7), I explored some common difficulties experienced by pupils with graphical techniques and discussed some of the opportunities for overcoming these through the use of computers. The skills fell into two main categories, those for creating and manipulating graphs and those for analysing and interpreting them. There was evidence from the APU surveys of performance in science (Archenhold, 1988) of the difficulties associated with interpreting the scales of graphs and their effect on the resulting appearance of the plotted data. Janvier (1978) reported pupils' low success in interpreting the meaning of graphs and suggested that this might result from an over-emphasis in teaching on the mechanical aspects of plotting graphs and comparative neglect of their global properties. My paper (Portfolio item 7) argued that software could support both areas of skill and generally amplify the value of graphs as instruments for investigating phenomena. An innovation contained in my argument was to propose a hierarchy of interpretative skills which I used as a framework for describing a progression of computer based tasks for developing these skills. A later paper, 'The computer as an aid for exploring graphs' (Portfolio item 8) developed these ideas further in the light of experience I gained from the early version of the Insight software (Logotron, 1992). Underwood (1994) has observed that, by automating routine tasks, ICT enables pupils to perform higher level thinking activity.
Similarly, Salomon et al (1991) have argued that the intellectual partnership between user and computer facilitates enhanced performance exceeding the constraints of conventional methods. The latter concept has underpinned my designs for the *Insight* software which have continually sought to optimise opportunities for promoting understanding. My paper ‘New data-logging tools – new investigations’ describes some teaching strategies for promoting thinking through analysing data (Portfolio item 9).

**Portfolio items:**


**Research into the effects and benefits of ICT**

Researches into the effectiveness of ICT have continually had to face the challenge of rapid advances in computer technology. The power of computers, in terms of their processing speed and memory capacity, has facilitated a trend towards increasingly sophisticated graphical user interfaces in software design. Although a benefit has been to lower progressively the threshold of technical skill needed to use ICT, it has posed difficulty for research projects in that the speed of such advances has tended to diminish the relevance of their findings. Two major studies, the ImpacT study of educational ICT use in England and Wales (Watson, 1993) and the PLAIT study using portable computers in Northern Ireland (Gardner, 1994), were conducted at a time of particular transition in software design (for example, the introduction of Microsoft Windows) and it can be argued that within a year or so of publication of results, practice in schools had moved on. In the context of such rapid technological change, there was a need to seek vision of underpinning theoretical principles to evaluate the direction of evolving practice. In the particular field of data-logging usage, there were significant advances in hardware and software design whose effect on practical science had not undergone rigorous evaluation in everyday classroom situations. Although many teachers held the belief that data-logging had the potential to improve the quality of pupils’ practical work in science, the
collected evidence supporting this belief was scarce. Thus the time was ripe for some serious investigation and appraisal of the supposed benefits of data-logging for learning in the classroom. My response to this initiated a series of three original research projects which form the main core of the oeuvre:

- **Classroom observations of data-logging** (Portfolio item 10) This project attempted to identify and measure beneficial changes occurring in practical lessons when data-logging methods are introduced. Observations were carried out in eight schools in the East Midlands.

- **OILS software evaluation** (Portfolio item 11) This project investigated the acquisition of data-logging skills by pupils working in small groups and using purpose-designed tutorial software. Six groups of pupils participated in a Leicestershire school.

- **NOF training evaluation** (Portfolio item 12) This was a broad study of classroom practice in the use of ICT based on lesson evaluation reports from a sample of 61 science teachers in 11 schools from all over England.

**Portfolio items:**


12. ‘Developing successful pedagogy with ICT – How are science teachers meeting the challenge?’ (with H. Finlayson) *Technology, Pedagogy and Education* (In press, accepted for publication in 2005)

The first project raised significant questions about the influence of the teacher on the effect of ICT in the classroom and developed my thinking about the criteria by which benefits might be identified and the skills required of pupils and teachers to use ICT successfully. This research contributed to my development of the tutorial software *Understanding Insight* (Logotron, 1999) designed for the acquisition of data-logging skills. The evaluation of this software was the focus for the second project which led me to a discussion of the influences of the teacher, software author and styles of teaching on learning (Portfolio item 11). The third project sought to identify and investigate the contextual factors in everyday classrooms which influenced the quality of outcomes when
using ICT. It drew from a much broader base of evidence compared with the first two projects, and made it possible to validate the models I had previously developed for describing the benefits and the skills requirements of ICT. It also provided valuable evidence for supporting my emerging vision of the principal elements of a successful pedagogy with ICT.

Concurrently with the research projects, I continued to develop the *Insight* suite of software which became an ideal vehicle for putting research findings into practice.

**Research methods**

Taken together, the three projects employed a variety of research methods, both qualitative and quantitative, conducted on scales ranging from the ‘micro’ to the ‘macro’. One project focussed on observing patterns of behaviour within whole classrooms, another studied the work of small groups in close detail and the third analysed written reports from a large number of teachers working remotely over a wide geographical area.

For the Classroom Observation Project (Portfolio item 10), the logical choice of method was a quasi-experimental approach, comparing the performance of two classes of similar ability, one using data-logging and the other using conventional methods for practical. In the event, devising a method of measuring the effect of data-logging proved to be a great challenge. One possibility was to compare end-of-topic test scores for the two classes and look for evidence of a better performance by the data-logging class. Alternatively, a qualitative approach through classroom observation could lead to the collection of a large amount of descriptive data on pupils’ activity, but in the absence of obvious criteria, it might be complex to analyse. In order to develop a sound approach to the research, I decided that a pilot study (reported in Portfolio item 13) was needed to test both ideas and provide pointers to suitable criteria for observation.

**Portfolio item 13:**

‘The use of IT in practical science – a practical study in three schools’ (with P. Wild)

In the pilot study I employed three methods; post-tests, structured observations and informal interviews. The inclusion of interviews with pupils and teachers provided valuable indications of their views on the advantages and disadvantages of the ICT method.

The ethnographic approach of the pilot study, in attempting to observe classes engaged in their normal schedule of lessons, suffered the disadvantage that I had no control over the content of the school-originated tests which consequently turned out to be an unreliable source of data. Thus, for the main study, I decided to abandon the use of tests and focus mainly on the structured observations to gain more data about the incidence of pupil discussion. Accordingly, the coding schedule instrument was refined as described in Portfolio item 10, page 134. During the pilot phase, much discussion of the interpretation of the categories ensued at moderation meetings of researchers and the coding instrument was further adjusted accordingly. The use of the instrument followed the principle of the Flanders interaction analysis system (Flanders 1970) such that, for each group of pupils, a code signifying the type of activity, was assigned at one minute intervals. By the end of a lesson a frequency profile across the categories was obtained. The coding was accompanied by recording notes of salient features of the activity or reflections on any aspects which might add value to the interpretation of results, such as information about the preparation of pupils, teacher interventions, teaching style, familiarity with software, established routines and so on. Throughout, the researcher was non-participant in lessons.

In contrast with the whole class observation method of the first project, a method consisting of close observations of small groups of pupils was used in the OILS Evaluation Project (Portfolio item 11, page 412). Here the purpose was to make qualitative observations intended to study in detail pupils’ responses to the software and to gain insights into their thinking. Each group of pupils received the full attention of a researcher as a non-participant observer. Observations were recorded in a naturalistic manner, noting the responses of pupils and their chief topics of discussion. Within the software design there were occasional prompts for teacher intervention to discuss pupils’ answers to tasks requiring reasoning or explanation and, to fulfil this, the researcher temporarily broke out of the non-participant role when required. After four sessions working on the software tutorials, pupils were given a semi-structured interview to ascertain their rationale and views on a range of aspects of the software-mediated tasks.
The analysis of the results from the interviews and observations required a more sophisticated approach than is usually possible when software evaluation is conducted through checklists of attributes. Such checklists (for example, Steadman et al, 1992) tend to focus on technical properties rather than educational issues and take no account of novel teaching strategies (Winship, 1988). Since my research aimed to illuminate the relationship between the software and its context of use, an interpretative approach to evaluation was more appropriate. A 'situated' approach to evaluation, fulfilled by the Perspectives Interactions Paradigm (PIP) proposed by Squires & McDougall (1996), proved to match well the needs of the study. In this, the knowledge, learning, tutorial and usability issues were examined by comparing designer-teacher perspectives, designer-pupil perspectives and teacher-pupil perspectives (Portfolio item 11).

The third project, NOF Training Evaluation, was conducted on a much larger scale than the previous two, drawing on over 300 lesson evaluation reports from teachers (Portfolio item 12). The format of reports followed a pro-forma supplied by the Science Consortium, which, although not specifically designed for research purposes, provided a rich resource of information and comment for examining a range of factors such as teaching strategies, planning rationale, management techniques, the response of pupils, teachers’ assessment of learning outcomes for pupils, their own learning gains in implementing ICT and opinions about the advantages and disadvantages of the software applications in use. As well as sustaining qualitative analysis, there was a sufficient quantity of data to support quantitative analysis also.

A pilot exercise with a small number of scripts established a framework for analysis consisting of an open coding system (Strauss and Corbin, 1998) which was then applied to the whole data set. The system used twenty nodes (categories) grouped under four main headings: management issues, operational skills, pedagogy and the perceived value of ICT. Analysis was performed initially by setting up a series of searches of the coded data, each of which collated comments from teachers under a common theme represented by a chosen coding node. Data organised in this way then permitted more refined searches, looking for common themes, correlations between different factors and measuring frequency patterns. This also facilitated the building of a database of examples of lesson episodes and significant quotations (as used in Portfolio item 12).
Research findings

Reflecting on the development of my presented research, the findings chart my quest to penetrate the superficial attractions of ICT to understand the principles which underpin its successful application in science teaching. The first research project posed fundamental questions about the criteria for identifying benefits to learning, the second prompted thinking about the distinctive contributions of the teacher and software author to pupils' learning and the third identified aspects of the teacher's classroom role which influence learning outcomes. The 'pupil as a learner' emerges as a common theme throughout, so it is unsurprising that learning theory should inform and illuminate the research results. In particular, the results endorse the constructivist model of learning, much promoted in science education by Rosalind Driver and her colleagues (Driver and Bell, 1986 and Driver et al, 1994). The constructivist model describes learning as a process in which knowledge and understanding is 'constructed' in a learner's mind by interpreting new experiences and attempting to reconcile them with previous knowledge. The significance of this model to ICT is that, appropriately employed, ICT offers numerous opportunities for developing an individual learner's personal engagement with scientific ideas. The themes of my research findings will be discussed in relation to this model.

Data-logging facilitates pupil discussion

Although the Classroom Observation Project (Portfolio item 10) was unable to demonstrate short term gains in pupils' learning in science, it clearly demonstrated that data-logging affected the character of pupils' activity during lessons; in particular, more time was spent in discussion of the effects in the experiments. The quality of the graphs appeared to facilitate this discussion, and pupils were more inclined to try variants of experiments. The magnitude of these effects was found to vary according to the topic of the lesson but, more significantly, the greatest effects were observed when pupil-centred working styles were prevalent; for example, pupils familiar with an investigative style of working generally spent more time in discussion. The significance of pupil discussion is its cognitive role in enabling pupils to clarify their thinking (Vygotsky, 1978), and although my research methodology did not attempt to measure pupils' learning directly, the incidence of discussion could be regarded as a positive factor contributing to learning.
The significance of my research – informing policy and practice

Although my earliest encounters with ICT made me sceptical about its educational potential, my subsequent research has not only found evidence which supports the assertion that ‘ICT is a good thing’ for science education but has also advanced understanding of the identity and nature of its benefits. For example, my research has demonstrated that:

- graphing software offers greater potential for analysis and interpretation
- data-logging is associated with more pupil discussion and thinking about results, particularly if the teaching style promotes this
- the accuracy and reliability of calculations performed in software facilitate reasoning
- simulations help to make abstract concepts real

More importantly, my work has advanced understanding of the circumstances in which the benefits of ICT, such as those listed here, are achievable. In particular, I have confirmed and amplified the mutual dependence of ICT and the teacher; actions of the teacher influence the success of ICT, yet the use of ICT will influence change in the teacher’s pedagogy. There remains a crucial role for many aspects of conventional teaching skill, albeit adapted to the context of using ICT tools, and this is an important reassuring factor in the training of teachers with ICT. However, the most successful examples of ICT benefiting learning occur when the teacher employs a teaching style which is informed by a constructivist model of learning. The mutuality of dependence is evident in the apparent strength of ICT tools, particularly in data-logging and graphing, to support investigative methods of learning which encourage questioning, evaluating and decision-making by pupils. My own software developments have sought to optimise support for such learning environments and, in general, I strongly advise software developers to embrace this principle.

My concurrent curriculum development activities have sought to put this understanding into practice and move frontiers by providing tools for further research. I have combined
Summary of Portfolio Items

1. ‘Microelectronics and physical measurement’ – Leicester University (1985)
2. ‘Interfacing programs’ – Leicester University (1986)
3. ‘The computer-assisted laboratory’ – Physics Education 22 (1987) 219-224
4. ‘A surprising sensor’ Micromath (Summer 1989) Vol.5 no.3, 41-43
5. ‘The computer as an aid to practical science - studying motion with a computer’
6. ‘IT in science in the National Curriculum’ – Journal of Computer Assisted Learning
7. ‘A Study of Pupils’ Skills of Graphical Interpretation with Reference to the Use of
   Data-Logging Techniques’ - NATO Advanced seminar (1992) University of
   Amsterdam.
   31-39
   61-68
10. ‘Data-logging - Effects on practical science’ (with P. Wild) Journal of Computer
    Journal of Science Education (2001) Vol.23 No.4 405-422
12. ‘Developing successful pedagogy with ICT – How are science teachers meeting the
    challenge?’ (with H. Finlayson) Technology, Pedagogy and Education Technology,
13. ‘The use of IT in practical science – a practical study in three schools’ (with P.Wild)
    School Science Review (1994) 75 (273) 21-28
    experience’ (with H.Finlayson) School Science Review (2003) 84 (309) 105-111
APPENDIX A

Additional publications – not submitted

Computer measurement: implications for school physics. 1989 NATO Advanced Workshop, University of Pavia, Italy
More value from graphs *Science Teacher Education*, October 1994

Oscillations Observed *Physics Review*, September 1994, 12-15
The role of computer-based measurement in practical science. March 1998 - A ciencia nas escolas e na vida (Forum Educacao – Lisbon, Portugal)
The use of software to explore experimental data. August 1996 - New ways of teaching Physics (GIREP – Ljubljana, Slovenia), 188-192
Promoting an investigative approach to learning science through IT. March 1994 - Rethinking the Roles of technology in Education - (ICTE; Massachusetts Institute of Technology, Boston), 385-387

Teaching Physics at Advanced Level - a question of style (with L. Newton) *Physics Education* 1996 31, 5, 265-270

Graphs in the service of physicists. Article in Physics in Mathematical Mood (36-39), 1999 - Institute of Physics
Graphs as bridges between mathematical description and experimental data. Sept 2001 (GIREP – Udine, Italy)


The exploration of experimental data with the aid of numerical models. July 2003 (CBLIS 2003 Cyprus)


Laurence Rogers - PhD summary
APPENDIX B

Summary of hardware inventions, published software and curriculum materials

H = hardware
S = software
C = curriculum materials

H  Interfaces for the BBC Microcomputer (1985)
S  Interfacing programs (1985)
S  *Budget Control* spreadsheet software (1985)
S  *Location Index* database software (1986)
C  Analogue Sensors Manual (1986)
S  *Find It in Physics* database software (1987)
H  Leicester Science Interface (1989)
S  *Science Measurement Toolkit* software (1989)
S+C  Practical Science with Microcomputers (1989)
S  *Sense & Control: Practical Science* software (1990)
H  Motion sensor (1990)
S  Motion sensor programs (1990)
C  Tools for Scientific Thinking (Motion Sensor Experiments) 1990
S  LogIT Pocket Book software (1994)
S  *Extra Sense* software for Deltronics serial interface (1994)
S  *Science Measurement Toolkit Extra* software (1994)
S  *MotionLab* software for Tandy portable computer (1994)
S+C  *Junior Insight* (1995)
S  Acorn Pocket Book data-logging software (1995)
S+C  *Understanding Insight* (1999)
S+C  *Control Insight* and *Junior Control Insight* (2000, 2003)
S+C  *Datalogging Insight* and *Junior Datalogging Insight* (2002)
S+C  *Insight Laboratory* (2002)
S+C  *Simulation Insight* (in preparation)
This booklet was written for science teachers who attended my workshops during 1984-85. It begins with a survey of currently available sensors and electronic measuring equipment and explains the physical basis of the technology. It goes on to suggest some of the new opportunities for science practical work afforded by the technology.

Chapter 4 offers a critique of the new methods, comparing their qualities with traditional methods of measurement and suggesting implications for classroom interactions and learning of science.

The second half of the booklet outlines experiments, describes sensor and interface circuits, and software for exploiting the computer measurement technology.
Leicester
Physics
Interfacing
Group

MICROELECTRONICS AND PHYSICAL MEASUREMENT

A Survey of the Use of Transducers and Interfaces in Practical Science

by Laurence Rogers

1985

UNIVERSITY OF LEICESTER
SCHOOL OF EDUCATION
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LEICESTER LE1 7RF
skills are needed to translate the use of the hardware and software into thinking activity which leads to enhanced learning of science. Since my original studies based on data-logging, I have succeeded in applying the distinction to all types of use of ICT in science (Portfolio item 15).

**Designing a software tool for acquiring ‘operational’ and ‘application’ skills**

The detailed identification of these skills inspired my development of the tutorial program *Understanding Insight* (1998), designed to support the acquisition of both types of skill through a constructivist environment. The program was developed in response to the government sponsored Open Integrated Learning System (OILS) scheme (NCET, 1994) to stimulate the development of tutorial software which embraced interactions and activities external to the software. Its constructivist credentials were manifest in the profusion of questions interspersed throughout the instructional material and opportunities for reflexive interaction. The program became the focus of the OILS Evaluation Project (Portfolio item 11) which yielded the following main conclusions:

- the software succeeded in developing operational skills
- the software provided a good basis for developing application skills
- the study supported the value of pupil-pupil talk
- the need for traditional teacher roles of challenger, adviser and respondent is undiminished by the use of the software.

Again the role of the teacher emerges as significant. Although the general rationale for tutorial software might appear to displace the teacher, my analysis argues that the ‘absent’ software designer shares some but not all of the teacher’s normal role: The program design provides a valid structure for achieving the skills learning objectives, but the teacher retains importance in amplifying pupils’ learning through interventions aimed at stimulating reasoned argument and metacognition. Explicit prompts within the software for teacher intervention were productive in achieving this. Discussion between pupils themselves, within working pairs, was also valuable, revealing ‘investigative’ dialogue, supporting the evidence reported by Underwood & Underwood (1990) that working in small groups at the computer is more beneficial to learning than individual use.

**Testing the pedagogical themes in wider classroom practice**

Thus far, the discussion of research findings has accumulated indicators of the value of ICT in science teaching, identified conditions conducive to pupils’ learning, described
specific skills associated with learning using ICT and highlighted the importance of the role of the teacher. I put these pedagogical themes to the test in the NOF Training Evaluation Project which gave access to a large volume of evaluation data.

**ICT supporting subject knowledge and thinking**

The data showed overwhelming recognition by teachers that ICT made subject knowledge more accessible. Teachers frequently expressed satisfaction in the effect of ICT as a facilitator for thinking and for fulfilling science teaching objectives in the vast majority of lessons. My paper ‘Does ICT in science work in the classroom?’ (Portfolio item 14) provides many examples of pupils’ achievements, as reported by teachers.

**Portfolio item 14:**


In my study, teachers remarked on the quality of results with data-loggers, the labour-saving aspects and the accuracy and reliability of the recording process, but they also referred to frequent links between these software properties with potential learning gains such as greater clarity of thinking, and encouragement for the interpretation of the results. In particular, real-time data-logging, offering the simultaneous presentation of graphs was regarded as being of great value to learning. Teachers’ notions of of ICT enhancing thinking skills are well supported in other research (for example; Chisholm & Wetzel, 1998; Knight & Knight, 1995; Underwood & Underwood, 1990).

**Teachers’ contributions to the success of ICT**

What aspects of a teacher’s teaching style and lesson design contribute to learning benefits with IT? The data provided numerous examples of successful teachers having adapted to the ICT context familiar teaching skills such as making links with previous work, setting targets, giving instructions, deciding when to intervene, giving the right sort and amount of help, prompting discussion, asking questions to probe understanding, sharing ideas, summarising what has been learned, and so on. This resonates with Kennewell’s description of the teacher as the ‘orchestrator’ of the influence of ICT on learning in the classroom, bridging the gap between potential and actual activity in lessons (Kennewell, 2001).
Many teachers recognised the value to pupils of personal interaction with computers, some expressing the desire to replace demonstration with more hands-on activity for pupils and some describing examples of actually ceding control to pupils. This was often associated with an investigative style of working which my earlier research had established a strong compatibility with ICT tasks. This synergy is also indicated in the major study by Sandholtz et al (1997) of the Apple Classroom of Tomorrow (ACOT) project in the USA, which demonstrated how ICT transformed classrooms to become more student-centred in teaching approach. Computers can be valuable knowledge providers for pupils working individually or in small groups, but the teacher retains an essential role of scaffolding pupils’ thinking. The balance of control between the teacher and pupil is a crucial issue for a pedagogy with ICT.

Case studies for promoting a pedagogy of successful practice

Embracing Mortimore’s definition of pedagogy as ‘any conscious activity by one person designed to enhance learning in another’ (Mortimore, 1999), it must be recognised that the introduction of ICT will inevitably have an influence on a teacher’s pedagogy. As Squires & McDougall (1996) have argued, the use of software introduces a third actor, the software author, who, despite physical absence, influences the nature and conduct of classroom activity through the design of the software. From the perspective of my research there is a dynamic relationship between the teacher and ICT; the teacher’s actions affect the success of ICT, but ICT will affect the way in which the teacher interacts with pupils. Together, these constitute a new pedagogy. In the book ‘Teaching Science with ICT’ (Portfolio item 15), I have sought to describe this pedagogy by exploring both aspects of the relationship; the potential of ICT to influence learning, and the actions of the teacher which maximise the exploitation of this potential. Part 2 of the book discusses the pedagogy through a series of case studies of the teaching of particular science topics using different types of ICT applications, covering information systems, publishing tools, visual aids, calculating, modelling and simulation tools, graphing and data-logging. Each case study analyses in detail how the ‘properties/benefits’ and ‘operational/application skills’ models can be translated into pedagogical practice: the properties of the ICT activity are identified, and the skills needed to realise the potential learning benefits are discussed from the perspectives of both pupils and teachers.
Portfolio item 15:


In each of my research projects discussed here, reflection on the effects of ICT has continually raised questions about the fundamental values and purposes of science education. Wider research has pointed also to the importance of the attitudes and beliefs of the teacher on their everyday practice in the classroom. Foremost amongst beliefs are those about how pupils learn. Teachers who embrace a constructivist model of learning are most likely to use methods which seek to understand what individual children think and foster understanding through discussion and collaboration (Bruner, 1999). Constructivist views underpin a belief in pupil empowerment. The studies of teachers’ use of ICT by Moseley and Higgins (1999) have established that teachers with such views tended to use small group work and easily adapted this approach to teaching with ICT. They provided good ICT opportunities for their pupils in both quantity and quality. The dynamic relationship between the teacher and ICT is emphasised in the longitudinal study of Sandholtz et al (1997) in their observation that the use of ICT has the effect of changing teachers’ pedagogy towards a constructivist position. My own research has identified a list of actions and decisions which are influenced by teachers’ beliefs: expectations and beliefs about pupils’ abilities, choice of objectives when designing tasks, assumptions about the teacher’s role in the classroom, teaching style and management style (Portfolio item 12).

Without doubt there is much synergy between a style of teaching founded on constructivist principles and the successes of ICT reported in my research (Portfolio items 10 and 12), so it is with no apology that my book (Portfolio item 15) makes strong advocacy of constructivist approaches. Constructivism is also implicit in all my software and curriculum developments, as exemplified in the ‘Teaching and Learning Guide’ for ‘Datalogging Insight’ (Portfolio item 16) which describes a variety of investigation type activities. The structure, presentation and explicit learning objectives of these activities attempt to keep thinking about the science at the forefront of pupils’ minds; the activities seek to exploit the unique qualities of the software and link them to learning needs appropriate to each topic.
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Science teachers have grown accustomed to a steady advance in instrumentation available in school science laboratories; there have been improvements in sensitivity, reliability, accuracy and general convenience. Gone are the analytical balances and ballistic galvanometers of a generation ago; some of the complex measuring skills required then have given way to simpler methods which enable greater emphasis on the phenomena under investigation. This trend has been especially welcomed when it has yielded greater clarity in teaching approach.

Recently, the pace of change in instrumentation technology has quickened largely in step with advances in electronics and now microelectronics. We have seen a proliferation of devices which can monitor and display virtually any physical quantity in the form of a digital readout. Not only do we have digital voltmeters and digital ammeters, but also digital thermometers, digital stop-clocks, digital fluxmeters etc. Unfortunately there is a danger that the type of problem where there is confusion, such as that between voltage and current, traditionally measured with a common appearance universal moving-coil meter, now extends to a host of other physical parameters, all of these being presentable on a common digital display. In a certain respect the digital readout offers a welcome release from our pupils' gross errors in reading analogue displays. However, as teachers, we must remind ourselves of alternative pitfalls such as assumed accuracy and the disguise of the physical nature of the measured parameter due to the common packaging of instruments.

The newer instrumentation techniques generally use transducers to convert the required physical parameter into an electrical signal. Once in electrical form the vast resources of the microelectronic technology can be employed to transform or process the signal into a form which suits the purpose of the investigation. The basis of this technology is less new than appears; for many years electronic instrumentation has played a vital part in the research programmes in industries such as aerospace, electrical supply, chemical engineering, energy exploration etc. The decisive new factor which
has propelled the technology into the educational sphere is its cheapness and consequent availability. It could be argued that Information Technology has come into being because it is available at a price we can afford. The hardware artefacts of the measurement branch of Information Technology are transducers, interfaces, microprocessors and computers, and through these physical measurement has acquired a greatly expanded role. Information Technology does not simply offer new high-technology alternatives to traditional methods; in the field of measurement it extends the range of measurement possibilities and increases the number of useful tasks we can perform with them. If we use the new techniques simply as a substitute for the old, with no obvious enhancement this represents a failure to recognise their true potential. In a responsible approach these are the sort of questions which should be asked:

"What is better about the new method?"

"What are we achieving now that was previously difficult, time-consuming or expensive?"

"Does the technique improve the quality of our pupils learning?"

For example, a thermistor should not be viewed as an alternative thermometer, but as a device enabling us to take hundreds of readings, or measuring temperature in inaccessible places, or measuring rates of change, or perhaps assisting the precise temperature control of an environment.

The purpose of this document is to look at what the new microelectronics-based measurement technology has to offer school science practical work, and to consider the major issues which assist evaluation of its use in the school laboratory. There are technical questions about the quality of measurement, and educational questions about the quality of learning experience. The development of laboratory practice in the use of this technology is in its infancy, and at this preliminary stage it is natural to expect initial ideas to be borne out of traditional experience. It is hoped, however, that this document gives some signposts to future innovation by drawing attention to the qualities of the new technology which deserve exploitation.
CHAPTER 2

ELECTRONIC HARDWARE FOR MEASUREMENT

This chapter considers the electrical components and devices whose use has helped to create the new measurement technology. The discussion is divided into two main sections:

a) transducers and their electrical output signals

b) electronic instruments which enable measurement of these signals

The purpose of the transducer is to convert a physical parameter into an electrical signal. The term 'sensor' is often used as an alternative to 'transducer' and the distinction between them is fairly arbitrary. However, for the purpose of this text, the term 'transducer' will be used to describe components which convert the required physical parameter into an electrical signal whose magnitude can be used to measure the parameter. The term 'sensor' will be interpreted more broadly to also include components such as switches which only yield on/off signals.

Electronic measuring instruments which accept the signals from transducers range from the simple (e.g. digital voltmeter) to the sophisticated (e.g. microcomputer).

TRANSDUCERS

It is a common principle in measurement to observe the effect of the required parameter on a physical property of a material e.g. it is the linear expansion of mercury in a glass thermometer which is used to indicate temperature; the extension of a metal spring is used as an indicator of force; electrical measurements are usually made by observing an effect of electricity such as heating, magnetic, chemical; in a moving coil meter, for instance, current is indicated by the deflection of an elastic spring acted upon by an electromagnetic force. In a very general sense 'transducers' converting one quantity into another are commonplace in measurement.

So it is not unnatural for a transducer to provide the starting point of an electronic measuring process, but in this case the transducer always converts the physical parameter into an electrical form or a form which is compatible with electric circuitry. Table 1 indicates the transducers commonly available.
<table>
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<th>TRANSDUCER</th>
<th>DEPENDENT PROPERTY</th>
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<td></td>
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<td></td>
<td>Cadmium sulphide cell</td>
<td>resistance</td>
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<td></td>
<td>Photodiode</td>
<td>conductivity</td>
</tr>
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<td></td>
<td>phototransistor</td>
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<td>Differential amplifier</td>
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<td>Oxygen concentration</td>
<td>Oxygen probe</td>
<td>voltage</td>
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<tr>
<td>pH</td>
<td>pH probe</td>
<td>voltage</td>
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</table>

**TABLE 1**

**PRIMARY AND DERIVED PARAMETERS**

This list covers a useful range of physical quantities which can be directly converted into an electrical signal. If these are regarded as primary quantities, numerous derived quantities can be subsequently calculated in software using combinations of primary quantities:

- volume,
- velocity,
- acceleration,
- momentum,
- energy,
- power,
- resistance,
- charge,
- frequency,
- humidity

It will be seen from later discussion that software provides the key to many new opportunities in measurement.

The breadth of measurable quantities expands still further if one explores the full versatility of the interdependence of many physical quantities. For example:

Fluid flow may be measured by causing the fluid to drive a rotary vane fitted with magnets; an alternating voltage is induced in a nearby coil and the flow rate is indicated by the frequency of this signal.
A low wind speed may be measured by observing its cooling effect on a fine current-carrying wire; temperature changes cause resistance changes in the wire which can yield an electrical signal.

The level of liquid in an opaque tube may be detected by timing the reflection of ultrasonic pulses by the liquid surface.

Sound resonance nodes in an air column may be detected using a thermocouple.

SIGNAL CONDITIONING

When considering the methods of deriving an electrical signal from a transducer it is useful to divide transducers into three categories:

- sources of e.m.f., a.c. or d.c.
- variable resistors
- variable inductance or capacitance

Before connection to an electronic measuring instrument, the signal will be usually required in the form of a d.c. voltage, typically in the range between 10 mV and 5 V. To achieve this 'signal conditioning' the output from the transducer is generally connected to an interface circuit, which is here referred to as the 'transducer interface'. For a d.c. source of e.m.f. such as a thermocouple, the interface need only consist of an amplifier. For variable resistive devices a simple potential divider network or a bridge network may suffice, together with an amplifier in the case of small signals. For a variable inductor an oscillator circuit is required. Transducer interfaces range from the very simple, requiring a few passive components to the sophisticated which might several operational amplifiers. In the next few years we can expect the increasing availability of transducers integrated in a single package with a signal conditioning circuit. (e.g. Light Activated Switch, Semiconductor Temperature Sensor LM35) At the present state of the art, construction details of suitable interfacing circuits are well documented elsewhere (See Bibliography) and apart from a few simple examples they will not be discussed here.
By far the greatest number of measurement applications use transducers which produce an analogue signal. The essence of an analogue signal is that its magnitude may vary over a continuous range of values. In contrast, for measurements which involve time or counting pulses, the signals are in a digital form where only two voltage levels are produced (usually 'high' and 'low'). Special purpose interface circuits are required for each type of signal. e.g. logic gates are suitable for digital signals whereas operational amplifiers are appropriate for analogue signals. Some measuring instruments only accommodate one type of signal (e.g. METER buffer box - analogue, CONTROLIT buffer box - digital), whereas others can accept both digital and analogue signals (e.g. VELA or UNILAB general purpose interface).
EVALUATION OF TRANSUDCERS

Transducers need to be scrutinised for their physical characteristics in the same way that conventional measuring devices ought to be, although, too often bland assumptions are made about the fidelity of traditional instruments. When evaluating the performance of a transducer, the following properties need to be considered:

- sensitivity
- accuracy
- linearity
- zero error
- calibration requirements
- response time
- reliability
- and repeatability
- size
- cost
- convenience of use

These properties need to be generally considered for the transducer together with its signal conditioning interface circuit.

SENSITIVITY

Where this is poor (i.e. the output signal is weak or changes in the output signal are very small), operational amplifiers are readily employed to obtain a large enough output signal. Since sensitivity to change in a parameter is the usual requirement, the presence of an unwanted steady 'background' component can be a great nuisance when amplified. In such cases, a difference amplifier could be used to offset the unwanted component.

For example, a semiconductor temperature probe (AD59KH) gives an output in proportion to degrees Kelvin where the first 273 output units may be regarded as redundant.

CALIBRATION REQUIREMENTS

When absolute values are required for the parameter being measured, the voltage output from a transducer system must be calibrated using standard conditions where the value of the parameter is already known. For example, a thermocouple may be calibrated using the fixed freezing and boiling points of water. It is convenient if the transducer system only needs calibration once for all time. Ideally a transducer can be calibrated in the manufacturing process as in the case of laser trimmed semiconductor devices such as the LM35 temperature sensor. When a transducer needs calibration before every use this is inconvenient, but the inconvenience is removed if only relative values will suffice; when the requirement is to show changes or make comparisons or look for relationships, calibration is less important.
LINEARITY

For a calibrated transducer system, most measurements are obtained by interpolation using calibration constants. This interpolation is most conveniently and accurately achieved if there is a linear relationship between the input parameter and the output voltage. Non-linearity not only introduces errors, but causes distortion in a pattern of results and can make it difficult to identify a relationship. Thermistors, light dependent resistors and photodiodes are well known as having logarithmically dependent properties. Their non-linearity can be compensated for in hardware through amplifier design or through software using algorithms or look-up tables.

ACCURACY

For calibrated measurements, the accuracy of the final measurement depends upon the whole chain of components starting with the transducer, through interface circuits to the measuring instrument; poor accuracy in the value of any individual component in the circuits will influence the final accuracy. Accuracy will of course be also reduced by a rough calibration or uncompensated poor linearity. However, the accuracy of a transducer system is often better than 1% of full scale value which is superior to that achieved in many conventional measuring instruments.

ZERO ERROR

This type of error is inherent in some devices such as the Hall probe which may output a small voltage when in a zero magnetic field. It is also sometimes introduced when using operational amplifiers and a 'zero adjust' control is necessary to eliminate it. Even after this, a gradual drift with time can occur and the effect invalidates previous calibration. When this type of problem is present, the only remedy is frequent checking of the zero condition.
RESPONSE TIME

Most transducers require a finite time to respond to any change in the parameter they measure. The simplest example is the 'inertia' of a temperature sensor due to its thermal capacity and the thermal conductivity of the packaging. As would be expected, a small size is conducive to a short response time. For temperature sensors, the response time is also considerably affected by the surrounding medium; e.g. for LM35 3 seconds in a stirred oil bath, 3 minutes in still air. Another important example is the light dependent resistor which takes a few milliseconds to change its resistance, especially when plunged into shadow. Sometimes, as in the example of a Hall probe, transducers have a shorter response time than that of the conventional method, thus enabling measurements to be made more quickly.

Response time only becomes an important issue when we want to monitor rapid changes; a measurement cannot be sensibly repeated until the response time has elapsed. This is of crucial importance when measuring short time intervals of the order of milliseconds; a suitable light-operated device for this purpose is the Light Activated Switch.

REPEATABILITY AND RELIABILITY

In a good measurement technique, single values are always treated with suspicion; pupils are often reminded of the importance of repeating measurements. It is by repetition that we can sometimes identify the presence of errors and ascertain the reliability of our results. Most of the factors discussed above contribute to the repeatability of a measurement which will inevitably suffer when there is a source of uncertainty or randomness. Mechanical transducers such as position sensors are potential problem cases. If a potentiometer is used, the wiper contact does not necessarily exactly return to a given position after a cycle of movement.

AN OVERVIEW

For a given parameter, it is very difficult to find a single type of transducer which possesses all of the most desirable properties. If found, it is likely to be expensive, and it is questionable that such a device would have universal application, for different applications of transducers are likely to place different importance on each of these characteristics. e.g. sometimes sensitivity to change may be more important than accuracy or linearity. When selecting a transducer, it is therefore necessary first to consider the requirements of the application. As an example of
the choices sometimes available, there are numerous alternative devices for measuring temperature and light, each with their particular merits:

Temperature:
- thermistor - cheap and simple to interface
- semiconductor - accurate
- thermocouple - low thermal capacity, robust, wide range
- platinium resistance - linearity.

Light:
- selenium cell - source of e.m.f., large area
- cadmium sulphide cell (ORP12) - cheap, good sensitivity
- photodiode - fast response
MEASURING INSTRUMENTS

Having converted a physical parameter into an electrical signal and, where necessary, used an interface to condition the signal to produce a suitable voltage, the next stage is to measure the voltage electronically. Here, there is wide choice of measuring instruments which can be employed in a variety of arrangements:

1. SIMPLE METHOD

Examples: Digital voltmeter, C.R.O.
Suitability: Direct measurements for manual recording.

The essence of this simple method is that the output voltage is connected directly to any analogue voltage measuring instrument.

2. MULTIFUNCTION INSTRUMENTS

Examples: VELA (Educational Electronics)
GiPSI (Griffin)
RM102 (Research Machines)
Suitability: Analogue and digital measurements
Automatic collection of data
Storage, recall and analysis of data
Portability, fieldwork

The main characteristics of the above examples of a multifunction instrument may be summarised as follows:

a) They can accept several analogue voltage signals simultaneously.
b) They contain a microprocessor circuit and are programmable.
c) They contain a memory which is capable of storing data.
d) The collection, processing and storage of voltage information is under the control of programs stored in the instrument.
e) Possess a simple alphanumeric display for examining stored data.
f) They can output both analogue and digital
voltage signals for further analysis by other instruments. However, there is a qualitative difference in the nature of the information transferred to these instruments:

i) The output for a chart recorder or voltmeter is an analogue voltage.

ii) The output for a C.R.O. is a periodic analogue voltage suited to the timebase of the C.R.O.

iii) The output for a computer is essentially coded data in the form of digital voltage signals.

3. GENERAL PURPOSE INTERFACE WITH COMPUTER

Examples of interface: UNILAB, I-PACK, AUCBE

Suitability: Analogue and digital measurements
Automatic collection of data
Storage, recall, analysis and visual presentation of data

This type of interface allows the computer to perform many of the functions of a multifunction instrument.
4. DEDICATED INTERFACE WITH COMPUTER

Examples of interface: TIMER, METER, HARRIS, GRIFFIN, various simple designs for school construction (see Chapter 5).
Suitability: By definition, each has a particular special use.

These computer interfaces have limited facilities which suit the desired application. When possible, it is convenient for the transducer interface and the computer input interface to be combined in a single package.

Scheme of use as for no.3

5. COMPUTER ALONE

Example: BBC Microcomputer only (analogue and digital inputs)
Suitability: Use is limited to transducer circuits of suitable sensitivity and voltage output. Since the computer inputs are unprotected, extreme care is needed to avoid possible damage due to improper connections.

The BBC Microcomputer is unusual amongst home computers in possessing an analogue-to-digital converter enabling it to ...
EVALUATION OF INSTRUMENTS

Now a closer look at the instruments which are used to accept and record signals from transducers or transducer interfaces. The schemes of use surveyed in the previous section indicated three types available:

1. Voltage measuring devices (digital meters, CROs)
2. Microprocessor measurement systems (VELA, GiPSI, RM102)
3. Microcomputer with interface

A full technical evaluation of these is beyond the scope of this manual, and interested readers are referred to publications from the School Science Service of CLEAPSE (Interfacing - Part C; available to member organisations only). However, a certain number of general attributes of measuring instruments will be mentioned in order to give an appreciation of some of the limitations they impose on the quality of the measuring process using transducers.

The technical attributes of instruments which must be considered are:

VOLTAGE INPUTS

A common characteristic of these is their high input impedance which makes them essentially voltage measuring devices. This is typically greater than 10 Megohm which makes them far superior to a standard laboratory voltmeter or Avometer. The range of acceptable voltage and maximum sensitivity varies between different instruments.

POLARITY

With the exception of the computer, most instruments accept both positive and negative voltages.

AC/DC

Again, with the exception of the computer, most instruments will handle AC signals but each has a different bandwidth (i.e. a different range of usable frequencies).
CONVERSION TIME

With the exception of the C.R.O., microelectronic instruments which handle analogue voltages incorporate an analogue to digital converter circuit (ADC) which requires a finite time to convert the incoming voltage into the digital code which is used by the instrument. The time can be as short as 2us or as long as 10ms. The chief consequences are on the maximum rate at which changing voltages can be sampled and on the shortest duration of transient signals which can be detected.

RESOLUTION

For instruments which use an ADC the smallest detectable change is chiefly determined by the number of bits in the binary code produced by the ADC. For an 8 bit code this implies a maximum resolution of 1 part in 256 (i.e. 0.4%) which suggests a precision of up to 3 significant figures. This is better than many conventional measuring instruments, however the accuracy of the ADC and associated circuits must not be taken for granted; the error is typically better than 1 part in 256.

CHOOSING AN INSTRUMENT

It is fairly straightforward to compare instruments on the technical grounds discussed above and on logistical grounds, cost and convenience.

1. Simple instruments such as a digital voltmeter and CRO are only really suitable when testing transducers or in experiments where manual recording of results is appropriate. This assumes that the use of a transducer, in preference to a conventional method, can be first justified on some of the grounds previously discussed for transducers (sensitivity, accuracy etc.).

2. Microprocessor measuring instruments are programmable, and this enables them to have many different functions (multifunctional). This versatility offers a wide range of potential uses:

   Simultaneous voltage measurement on several channels
   Recording transient events
   Logging data
   Counting pulses
   Measuring time intervals and frequency.
The sensitivity to input voltages is selectable and the ADC conversion time is usually fast enough to handle audio frequency analogue signals. The instruments are portable and, when fitted with a 'back-up' battery for the memory, are well suited to field work. Stored data can be analysed using a digital readout or an external CRO, and further programs stored on EPROM chips in the instrument offer an expanded range of analysis techniques. The permanent storage of data is only possible by transferring it to a computer and then to a floppy disc. In terms of cost, multifunction instruments are currently between one third and one half of the cost of a microcomputer system.

3. With the exception of the BBC Microcomputer, computers generally need an input interface if they are to be used for measurement. The main functions of such interfaces are to provide analogue to digital conversion, and to give protection to the computer against the connection of unsuitable voltages.

The use of direct connections to the BBC Micro has limitations due to all the factors listed above:

- slow conversion time (10 ms)
- small range of input voltage (1.86 V maximum)
- negative voltage input is prohibited

Direct connections also require extreme care to avoid internal damage to the computer. A reasonable degree of protection can be provided by the use of single purpose connection boxes, dedicated to the use of one type of transducer or even more specifically for use with one particular experiment. Some examples of these are described in Chapter 5. In the hands of pupils, the only satisfactory alternative to these is to use a 'buffer box' or interface circuit. Simple analogue interfaces (e.g. METER or Harris A to D Converter) offer one channel of voltage input at a single sensitivity. More facilities can be purchased on a sliding scale of cost up to the general purpose interfaces which offer both digital and analogue inputs on several channels with a range of input sensitivities, in some cases entirely under software control.

At the technical level, the choice of interface is simply determined by the intended use; clearly the general purpose interface offers many facilities and can be extremely flexible, but there is often a measure of redundancy in the use of its facilities and questions need to be asked about the 'cost' of this. On the other hand, a simple interface has limitations but it is fully utilised while in use.
Unfortunately technical grounds are not the only ones to be considered when choosing an interface for a computer; the usefulness of an interface is heavily dependent on the availability of suitable software. Good software opens up enormous potential for computer-based measurement, but without such, this potential is not realised. The implications of software will be discussed in the next chapter.
CHAPTER 3
NEW EXPERIMENTAL OPPORTUNITIES

There are two main respects in which the use of transducers, microelectronics and computing facilities opens up a wide range of new opportunities in experimental work:

1. The range of possible measurements in the school laboratory has been extended by the functions of microelectronic instruments and the physical properties of some transducers.

2. Our ability to use data collected from experiments can be enhanced by software.

Put in another way:
Through hardware our range of perception has increased; through software a higher order of thinking is possible.

Or yet another:
We can find out more, and can do more things with it.

EXTENDED PERCEPTION

Sensitivity to very small signals has increased with an ability of microelectronic devices to measure very small voltages and currents, a.c. and d.c., with excellent transfer characteristics. This is often achieved by the use of integrated circuit amplifiers which have a high input impedance and low output impedance which ensures an efficient transfer of the available signal. The use of appropriate integrated circuit amplifiers minimises the effect of changing ambient conditions which could produce noise or drift.

The timescale of measurements has been extended in both directions, from very short-lived transients to events occurring over a long period of time.

Large amounts of data can be collected and stored with great ease. For example VELA can store up to 4000 units and a microcomputer could be configured to store up to ten times this amount. The wise use of such large amounts of data becomes a serious question and a satisfactory answer must demand discrimination and judgement on the part of the user. One response is to increase the emphasis on making comparisons, looking for patterns, or looking for salient features.

As a consequence of the large range of possible time
measurements, the rate of data collection can be varied over a correspondingly large range. Some instruments can record a new value every 30μs, giving a maximum sampling rate of 33000 values per second. A good oscilloscope can of course display changing data at rates 100 times faster than this but, without great expense, it lacks any storage facility. Any sampling rate faster than, say, 1 value per 10s can outperform a human observer recording manually. The lowest possible sampling rates of some instruments are only limited by the practical usefulness of measurements collected over very long periods of time.

'Simultaneous' measurements of several quantities can be made. True simultaneity may not exist since those instruments having more than one input channel usually read one channel at a time in a cycle. However, this effect only becomes critical as the cycle period approaches a similar magnitude to the sampling interval.

EXTENDED DATA USAGE

It is through software that many new opportunities are created in the methods of collecting, storing and using experimental data. For a multifunction instrument, the utility software is permanently held on EPROMs within the instrument, whereas for a computer, special software must be loaded before each use.

1. DATA LOGGING

Under software control, automatic recording of data is possible; the common jargon for this is 'data-logging'. What this means in practice is that one or a number of transducers have been set up to send signals to the handling instrument. The instrument is programmed by the user to read and store the signals at defined regular intervals, and once the collecting process is initiated, the user has no further part to play in the measuring process until the logging sequence is terminated. Of course, the user must still manipulate the apparatus, but the observation and recording of readings is handled automatically. This is ideal for recording transient phenomena where the requirement is to obtain hundreds of readings during a short-lived event. Assuming that manual observation and recording cannot be realistically performed more than about one reading every 10 seconds, any automatic rate faster than this promises to increase our ability to collect data.
At the other extreme, experiments which require measurements over periods longer than, say, 30 minutes are more satisfactory through automatic data collection. Once set up and running, such experiments can be allowed to proceed for several hours without attention. This is particularly suited to environmental topics involving slow changes and long time-scales.

2. TIME 'WARPING'

For time-dependent data, data-logging offers the ability to 'stretch' or 'compress' time. Data can be collected at a certain rate and then reviewed and analysed at a convenient different rate. Thus, a few hundred items of data collected for a transient lasting two seconds, can be analysed at leisure over several minutes or longer. Similarly, data collected over a period of hours is conveniently reviewed in a few minutes.

3. PRESENTATION OF DATA

The main software methods of handling collected data feature either numerical analysis or visual display or both. As well as its processing ability, the microcomputer offers considerable scope for the visual presentation of results. Largely because of this, all multifunction instruments incorporate a data socket for connection to a microcomputer enabling the transfer of stored data to the microcomputer for subsequent sophisticated handling through software.
4. DISPLAY OF DATA

Carefully designed forms of VDU screen display can readily give 'added value' to the presentation of results. The best software available pays much attention to screen layout and makes judicious use of graphics and colour. The following is a summary of the chief features which have been commonly exploited:

a) A LARGE DIGIT display of results is very suitable for demonstration work

b) LABELS of physical quantities can be used to clarify the meaning of displayed values.

c) Different COLOURS can be used to distinguish different parameters.

d) A BAR or LINE representation of the magnitude of an analogue value helps to give a 'feel' to the value and its significance.

e) A BAR CHART similarly conveys an immediate impression of the comparison of several values.

f) A GRAPH showing the relation between two parameters is a common useful aid which enables a quick recognition of salient features and any pattern in a set of results. Several sets of data can be plotted in different colours simultaneously and comparisons made.

g) A DIAGRAM of the apparatus with results superimposed can help to add meaning to the results.

When the microcomputer is used to log data, most of these software techniques can be employed during the actual process of data collection. If however time is one of the collected quantities, the software has to be very carefully designed to avoid introducing errors in time values due to the finite time required by the computer to modify the content of the screen display. These errors are usually unacceptable when logging at very fast rates; the only available solution for the software is to first collect all the required data during an inactive screen display, and then present the results retrospectively on the screen in the chosen format.
5. PROCESSING OF DATA

The microcomputer as a calculating aid has numerous applications. Its rapid speed of working makes it ideal for processing large amounts of data. Thus, for example, from a set of stored values for voltage and current it is a straightforward matter to generate a set of corresponding values of power or resistance. In this example the calculations are simple enough to perform manually, but it is more appropriate to use a computer when dealing with hundreds of values. 'Spreadsheet' programs can be useful when a routine sequence of calculations needs to be applied over and over again to a large number of data items. However, the typing-in of data might be a drawback if the spreadsheet facilities are not also linked to the data-gathering software.

There are many derived quantities which are conveniently calculated from primary measurements:
- velocity and acceleration from distance and time
- momentum and kinetic energy from mass and velocity
- electrical resistance and power from voltage and current
- frequency from time

The calculation of derived quantities need not be restricted to the retrospective treatment of masses of data; the immediate presentation of calculated quantities can usefully contribute to a discussion about an experiment, perhaps considering its design. For example, the velocity of an object passing through a light gate can contribute to a discussion about uniform velocity and friction-free conditions.

6. ANALYSIS OF DATA

Computer generated graphs are an extremely flexible tool for analysing data. Patterns and relationships can be identified, visual comparisons between several sets of data made, and significant data extracted e.g. measurement of peak values, the ratio between selected values, values associated with crossing points, points of inflexion.

In software it is a straightforward matter to interchange axes, change the plotting scale, select false origins etc. and when simultaneous measurements of more than two parameters have been made there can be a choice of which two parameters are to be plotted against each other.
When seeking relationships between different physical quantities, software can conveniently calculate squares, reciprocals, inverse squares and logarithms etc. Software routines can be used to calculate 'best-fit' straight lines, gradients at selected points, areas under curves, average values, statistical quantities, ratios, etc. Such flexibility provides plenty of scope for alternative ways of using and comparing data; with the ability to generate and manipulate graphs so rapidly, the user need not be constrained to plotting a graph in just one particular way. Altogether, these types of applications software provide us with powerful diagnostic tools.

7. 'SIGNAL CONDITIONING' THROUGH SOFTWARE

In some cases, the 'raw' signal from a transducer is not immediately convertible into a meaningful value for a physical quantity. Signals which are too large or too small are best attenuated or amplified by hardware devices, but there are a number of requirements for which software can also play a part.

A simple example is that of inverting a digital signal. Supposing a light sensor yields a 'high' signal when in shadow, this may be used to start a software time measurement in the computer. The program is easily modified to reverse this condition so that brightness starts the timing. Further modification could instead use a transition from bright to dark to activate timing.

Another simple software technique can be used to average several values in order to reduce the effect of random fluctuations from whatever cause. This technique is often needed when reading values returned by the analogue port of the BBC Microcomputer which exhibits appreciable electrical 'noise'. In research, rapid averaging techniques are used to enhance very weak signals. Here, several successive cycles of the signal are added together, and the cumulative effect is to build a signal of larger amplitude. In contrast, because of its randomness, the background noise undergoes no such reinforcement.

It is possible to calibrate some transducers in software. The signals returned by the device when subjected to standard conditions can be used to calculate calibration constants which can be applied to all subsequent signals. A thermocouple could be calibrated in this way, as could a potentiometer for measuring angle. If accurate voltage readings are required from the BBC analogue port, a calibration
reading can be obtained from a precision voltage reference diode. (See Experiment 2 in chapter 5.)

A related technique is to subtract an 'offset' value from an incoming signal. e.g. a Hall probe usually outputs a small signal in zero magnetic field. Software can be made to automatically subtract this from all subsequent readings. In a similar way a 'tare' control can be simulated. e.g. a value for ambient lighting could be subtracted from readings from a light transducer, or a room temperature value could be subtracted from readings from a temperature transducer.

A further standardisation technique uses a 'look-up' table held in software. The output from a non-linear transducer can be compared with that of an accurate standard transducer at many points in its working range so that a table of accurate values corresponding to the 'raw' values could be built up and stored. By reference to such a 'look-up' table, any signal from the transducer can be converted into an accurate value. A useful example of this uses the 'curve-matched' thermistor. (See Experiment 3 for a fuller description.) Here the look-up table consists of 256 temperature values corresponding to 256 equally incremented voltage readings. The voltage from the thermistor circuit is used to identify a position in the table, then the temperature value may be read out.

8. STORAGE AND RECALL OF DATA

Data stored in a computer will of course be lost when the computer is switched off. However, the familiar process of permanent storage of computer data on cassette tape or floppy discs is equally available to data collected from experiments. A printer can add further permanency to the data by printing it in tabular or graphical form. Several data handling software packages feature these permanent storage facilities.
9. CONTROL

All the references made to software usage so far have assumed that the computer is a recipient of electrical signals or data. Although it is beginning to depart from the main concern of this inquiry into electronic measurement, it is appropriate to indicate how the computer can be used to output electrical signals under software control. It further illustrates a feature of some of the descriptions above where both software and hardware can be seen as providing alternative means of implementing a function or condition.

An electric oven heating element can be controlled by a relay which can be energised by a signal output from a computer. Using a temperature sensor to monitor the oven temperature, software can be used to maintain a steady temperature at a selected value by controlling the relay. Thus a thermostat can be simulated. Of greater interest is the ability of software to control the rate of temperature increase or to define a cycle of temperature changes.

An instrument with an analogue output has the ability to output an electrical wave whose profile can be defined in software. One such application of this is as a ramp generator or 'saw tooth' function where the output voltage increases at a linear rate within each cycle. Applying such a voltage to a device such as a transistor or diode, the characteristic of the device may be obtained entirely under software control.
CHAPTER 4

EDUCATIONAL IMPLICATIONS

The existence of the new measurement technology and its current growth in industrial and commercial application cannot be ignored; the question of concern to science teachers is what place it should be given in the school science laboratory. In attempting to identify the implications for teaching and learning, the following questions could be posed:

What are the new opportunities for teaching and learning?

What new methods of working are appropriate or necessary?

What are the dangers of adopting new methods?

1. NEW AND OLD PRACTICAL SKILLS

The previous chapter has surveyed the range of opportunities offered by hardware and software. To take advantage of these, pupils need to be taught appropriate manipulative skills which are required to confidently and competently handle the new instruments. Experience suggests that pupils assimilate these with generally greater ease than do their mentors of greater maturity. However, with the increased use of electrical devices, there is an even more important role for the teaching of a disciplined approach to assembling and understanding electric circuits; indiscriminate juggling of electrical connections is clearly unacceptable. So, in many cases the new skills must take their place alongside more traditional laboratory skills; perhaps some traditional skills will be made redundant, but a broader view is of an extended range of measuring methods so that more often it will be necessary to select the most appropriate method for the job. For example, the humble metre rule is still the most appropriate instrument for measuring distance in the vast majority of cases; the use of a position sensor should only find application when it is able to satisfy special requirements like those for a moving object.

Often, the traditional method gives a stronger 'first-hand' experience of the phenomenon, and pupils should not be deprived of this. In such cases, the microelectronic method may only be appropriate as an accessory providing an extension to the 'basic'
experience. An example of this is provided by the experiment to monitor the discharge of a capacitor (Experiment 2): It is best for pupils to perform the 'manual' version of the experiment first; the value of the computer method follow-up is to assist the close study of the effect and enable rapid comparisons to be made under varying conditions.

2. NEW ACTIVITIES AND LEARNING ROLES

For two reasons, the tasks for pupils in the laboratory need to be reviewed when using data-logging methods:

a) The pupil should not be made into an idle onlooker.

If the experiment is to be a class demonstration, all the skills of a teacher to involve the class or group are as important as ever. The use of microelectronics for gathering data should not preclude those demonstrating techniques which challenge pupils to think by posing a problem, get them to speculate, invite direct handling of apparatus, or share responsibility. For individual pupil work, the tasks should be designed so that the computer or multifunction instrument does not eliminate the involvement of the pupil; when period data-logging is necessary, complementary activities need to be planned such as qualitative observation exercises, discussion problems, written work etc.

b) The software methods for analysing data can offer new insights.

Since formerly tedious, repetitive or time-consuming tasks are speedily performed, pupils can be called upon to exercise process skills involving, comparing sets of data, looking for a pattern in results, making inferences, or making design judgements. On a computer, the skills associated with obtaining information from graphs are considerably extended; choosing the functions to be plotted, inverting the axes, changing the scale, moving a false origin, measuring gradients, areas and peak values. It is in the use of data that there are important new opportunities which help to shift the emphasis away from actual numerical values towards an appreciation of their significance.

3. INFORMATION TECHNOLOGY

New methods for collecting and handling data are the central theme of Information Technology. It is appropriate to show pupils that when applied to physical measurement, a significant emerging factor is the
overlap between the roles of hardware and software so that to a degree they are interchangeable. It was shown in the previous chapter that software techniques can be applied in various ways to simulate functions which are normally implemented using hardware:

- Temperature control: thermostat
- Signal conditioning: calibration and linearisation of devices
- Flexible timescale of measurement
- Programming of electronic circuits to possess particular physical properties.

In short, the role of software is so flexible that it extends the range of 'devices' available to engineers. We do well to give pupils an appreciation of this fact through the applications which they experience in the school laboratory.

4. HOLDING ON TO REALITY

There are a number of dangers associated with the increased level of sophistication in measurement. The most obvious problem is the apparent remoteness of the measurement from the actual physical quantity under consideration. Unfortunately, the measuring process can be easily disguised by the prevalence of 'black boxes' and electrical circuitry. Care has to be taken to compensate for this so that pupils can more strongly identify the physical nature of the measured quantity and make the conceptual connection with the digital or graphical display. For simple primary quantities such as light intensity, temperature, time, position and magnetic field etc., a simple approach through informal experimentation can help towards this. However, for quantities which have traditionally proved conceptually difficult, there is no substitute for the role of equally traditional teaching skill. Chief amongst these problem cases are the popular confusions between current and voltage and between velocity and acceleration. In the latter case, involving two 'derived' quantities, carefully designed software, which allows the steps in the derivation to be easily followed, can greatly assist towards understanding.

Another danger is sometimes overlooked during conventional measuring techniques; the integrity of the data obtained from a microelectronic system cannot be taken for granted. Teachers should not lose sight of the limitations of each component in the measuring system, and for many pupils we have a duty to encourage questioning and discussion about issues such as accuracy, linearity, calibration and resolution.

A further danger is not at all new but is ever present for unsuspecting and undiscriminating pupils; a lack of
common sense towards the size and order of magnitude of values obtained from instruments. One would hope that pupils develop and instinct for spotting 'rogue' values produced by transcription or scaling errors, but continued training is needed to appreciate the number of significant figures associated with any measured quantity. Like calculators, computers can display calculated numbers to a large number of decimal places and care is needed to restrict the number of digits according to the accuracy and resolution of the components involved in the measuring process. Thus if a temperature probe has an accuracy of +0.1 degC over the range 0 to 100 degC, no significance can be attached to the display of any digits beyond the first decimal place. Moreover, if the ADC converter only resolves to 1 part in 256 for the output range of the probe, this further reduces the effective accuracy to +0.4 degC.

5. CHOOSING THE RIGHT LEVEL

The preceding discussion has dwelt much on the power of software to perform useful tasks in manipulating and processing data. The potential is so great that, taken to an extreme, the user, after pressing a start key, could be reduced to being a mere onlooker. This would clearly serve no useful purpose and a sensible rationale for software design must involve a retreat from the bounds of possibility to a level of sophistication which will give the user an active thinking role. It is very important for software design not to overuse the power of the computer. As far as possible, the tasks should be first defined on the basis of educational objectives and it is these which should dictate the level of sophistication of the required software. For example, in an experiment to study the motion of a simple pendulum (see Experiment 5), it would be possible to design a computer program which could perform all the suggested analytical tasks automatically i.e. test for the constancy of the period, plot amplitude values against maximum velocity. Instead, having determined that these tasks should be part of the pupil's activity, the software would be designed to provide convenient tools for those tasks, such as the rapid selection and recall of stored values, calculation of gradients, and function calculations on data such as squares or reciprocals.
6. THE WAY AHEAD

In the foreseeable future we can expect continued advances in both the hardware and software available to schools:

Hardware is likely to become cheaper, of higher technical quality and simpler to use.

Software is likely to become even more powerful and sophisticated.

As teachers, we must ensure that these advances are matched by equal progress in the educational uses of the technology. Developments should not replace conventional methods for the sake of replacement but instead use the special qualities of the technology. Thus, for example,

we can overcome some of the limited skills of certain pupils in plotting graphs;

through computer graphics we can use the power of visual imagery to assist understanding;

we can use software in the collecting and processing of data thereby increasing an emphasis on process skills such as interpreting data.

These are a few of the benefits discussed in previous chapters and paragraphs, but in embracing these opportunities we must also not lose caution over the technical and educational integrity of the technology. Above all, future development should be guided by educational judgement rather than the wildest dreams of exotic hardware and software design.
CHAPTER 5

SOME SIMPLE TRANSDUCER APPLICATIONS

The discussion of the previous chapters has covered a range of technical and educational issues concerned with the hardware, software and laboratory use of microelectronic measuring techniques. The main purpose of this chapter is to illustrate some of these issues and put them into context by considering some specific ideas for applications. Simplicity has been emphasised throughout in the hope that readers will be encouraged to try these experiments for themselves. Transducers have been chosen with minimal interfacing requirements and the cost of components is considerably less than that of equivalent commercial products. A small amount of circuit construction is called for, but the level of skill required is very modest.

The experiments to be described all use simple transducers connected directly to the BBC Microcomputer. This computer is commonly available in schools and stands alone from other computers in possessing a built-in facility for measuring d.c. voltages in external circuits. However, care has to be exercised to avoid causing internal damage to the computer when making direct connections. (Readers are referred to the Sunderland File (see Bibliography) for a full discussion of interfacing techniques for the BBC Microcomputer.) Therefore, for each experiment, a special purpose interface circuit is described which makes connections both simple and reasonably robust against mistakes. If these circuits are constructed in a school, this tailor-made approach offers a combination of low cost and high utilisation of components.

These applications may be adapted to use other computers with a suitable analogue input interface attached, or other measuring systems. For example, VELA could be used, but most of the analysing tasks would be performed using an oscilloscope.

Software plays a prominent role in the examples and uses ideas developed in the Leicester Physics Interfacing Group. Program listings of the main features are given here, but developed versions are obtainable from the addresses given in Appendix B.
EXPERIMENT 1: CONVECTION IN LIQUIDS

Outline:

Two thermistor probes are used to monitor the temperature at the top and bottom of a beaker of water. A graph of the two temperatures is displayed on the screen as the water is heated in a number of different ways.

Apparatus:

- 2 thermistor probes R-T curve matched type 100K RS 151-243
- 2 glass tubes 30 cm
- Glass beaker 1 litre
- Immersion heater 12V
- Power supply 12V
- Thermistor Interface circuit

Description:

The thermistor probes are fitted inside the glass tubes so that they may be clamped in position in the beaker as shown. A position is chosen for the heater and heating is commenced. At the same time the program starts logging and displaying the two temperatures, each in a different colour. The rate of rise of each temperature and their difference is shown to depend on the positions of the two probes and the heater. The effect of stirring can be observed, and if the positions are altered, a new set of curves is obtained. The data for each set of curves can be saved on disc.
Discussion of the experiment:

The emphasis in this experiment is on simple investigations. The simple ideas can be easily extended. The rate of heating of different liquids could be investigated, the rate of cooling with different external surfaces, a software utility to measure the gradient at selected points could be used to investigate the relation between the rate of cooling and the excess temperature above room temperature.

Discussion of the apparatus and software:

The recommended bead thermistors are not of the cheapest type but are manufactured to a specified resistance-temperature characteristic which removes the need for individual calibration. The use of thermistors provides a good opportunity to illustrate to pupils how software can be used to cope with the gross non-linearity between temperature and input voltage. In this case a look-up table in software is used to convert the analogue port reading directly into temperature. There are 256 single-byte values in the table, each value being double the numerical value of the celsius temperature. The port reading is used to point to a value in the table which is divided by 2 to give the temperature to a precision of 0.5 C. This precision is compatible with the resolution of the port reading and with the accuracy of the thermistor itself. The use of single bytes (maximum value 255) in the table keeps the computer memory storage requirement to a minimum. The technique is very fast and is particularly appropriate when the mathematical relationship between the two quantities concerned is complex (in this case between temperature and voltage).

Summary of features:

Example of signal conditioning through software
Logging data over a period of minutes or hours
Two simultaneous sets of measurements compared
Pupil tasks: observation, interpretation, comparison, analysis of graph
Software: Look-up table used to decode voltage
Results both displayed (graph) and stored
Redisplay and recall of stored data
Calculating aid: gradients
Main advantages: Collecting data from two sensors over a period of minutes or hours
Clear visual comparison of simultaneous values
Circuit diagram:

Thermistors
Construction details: Thermistor Interface

The interface circuit is constructed by soldering components on to a stripboard which can be housed in a plastic box fitted with 4mm sockets. Connection to the computer is through a ribbon cable to a 15 way D-type plug which is inserted into the analogue port at the rear of the computer.

The thermistors each need to have soldered lead connections and for electrical insulation should be fitted inside a PTFE sheath with the bead glued in position at one end. Suitably mounted thermistors can be obtained from Cleveland I-Tec (See Appendix A).

Parts list:
- Resistor 100K 1% 2 off
- Plug 'D' type 15 way RS 466-185
  4mm 4 off
- Cable 5 wide ribbon
- Box

![Thermistor Interface Diagram]
EXPERIMENT 2 : CAPACITOR DISCHARGE

Outline:

The decaying voltage across a discharging capacitor will be logged, and a graph plotted on the screen. The data will then be analysed to study the characteristics of exponential decay.

Apparatus:

- Capacitors 500uF, 250uF, 100uF
- Resistors 10k, 22k, 47k
- Switch push type
- Capacitor interface circuit

Description:

A capacitor and resistor are connected to the interface circuit as shown. Closing the push switch causes the capacitor to charge up to the voltage Vref (1.85V). Opening the switch causes the capacitor to discharge through the resistor. The software reads the voltage continuously and displays it as a graph against time. The main emphasis in this experiment is in the analysis of the graph. The software allows the user to:

a) pick out values from different points on the graph
b) calculate the ratio of two values
c) measure gradients at selected points
d) calculate the area underneath the curve.

These utilities enable the user to make the following investigations:

a) Investigate the ratio of voltages at equal time intervals to test the constant ratio property expected for an exponential \( \frac{V_0}{V_1} = \frac{V_1}{V_2} \)
b) A similar exercise can be performed on the gradient of the curve at selected points.
c) The total charge stored on the capacitor can be
calculated for the screen area underneath the curve and, when the experiment is repeated with different combinations of capacitor and resistor values, their effect on total charge and decay time can be studied.

Discussion of the Experiment:

This experiment is most suited to 6th form pupils working individually or in small groups. It is a standard A Level exercise and it is right that the pupils should first have the experience of the traditional manual version before using this computer version. The software is designed not to do everything for the pupil but to provide him with utilities to perform analytical tasks. The ease with which the experiment may be repeated allows the pupil to make an extended study of the effect of the variables involved.

Discussion of the apparatus:

A single purpose interface may be constructed to which are connected an external capacitor and resistor. Since the number of components is so small, an analogue port extension box may be preferred with components plugged in using 4mm connectors.

The voltage reference diode is included to provide a means of calibrating the voltage readings. The calibration is performed entirely within the software; the diode gives a standard voltage of 1.22V and being permanently connected to analogue channel 1, a standard value is always available for calibrating readings at the other channels. The suggested component values have been selected to give time constants in the range 1-24 seconds, which is convenient for the graphical display.

Summary of features:

Example of simple voltage measurements
Transient phenomenon investigated
Pupil tasks: observation, interpretation, prediction, analysis of graph
Software: Results both displayed (graph) and stored
Redisplay and recall of stored data
Calculating aids: ratios, gradients, areas
Main advantages: Computer aided analysis of data
Construction details: Capacitor interface

The interface circuit is constructed by soldering components on to a stripboard which can be housed in a plastic box fitted with 4mm sockets. Connection to the computer is through a ribbon cable to a 15 way D-type plug which is inserted into the analogue port at the rear of the computer.

Parts list:
- Switch: push to make RS 337-914
- R2: 3K9
- D1: precision voltage reference 9491 RS 283-283
- Plug: 'D' type 15 way RS 466-185 and cover
- Socket: 4mm 2 off
- Cable: 5 wide ribbon
- Box

Capacitor Interface
Circuit diagram:

Capacitor Discharge
EXPERIMENT 3: VOLTAGE-CURRENT RELATIONSHIPS

Outline: The current-voltage graphs for 3 different lamps will be plotted directly on the computer screen. The lamps will be compared for the effects of temperature and resistance.

Apparatus:
- Battery 4.5V
- MES lamps 3.5V 0.3A, 6.5V 0.3A, 12V 2.2W
- Rheostat 11 ohm
- Voltage-Current interface circuit

Description:
Having plugged the interface circuit into the analogue port of the computer, the rheostat is connected to the battery as a potential divider and the voltage output from this is connected to the interface circuit as shown. The rheostat is used to vary the current through the lamp. The most interesting effects are achieved by increasing the voltage to the lamp slowly and then decreasing it slowly. The computer software reads two voltages $V_1$ and $V_2$ continuously; $V_1$ is proportional to the current through the lamp and $V_2 - V_1$ is proportional to the voltage across it. These are used as coordinates to plot points on the screen continuously so that as the rheostat is adjusted the pattern of the voltage-current relation is shown by the cumulative effect of the points. The procedure can be repeated for each of the other lamps in turn, superimposing their results on the screen in different colours. Pupils can be asked to think about:
   a) the changing slope of the graph
   b) the different curve produced when the voltage is reduced instead of increased
c) the dependence of the curves on the rate of change of voltage
Pupils should also observe the visible behaviour of the lamp at the critical part of the curve where the slope changes rapidly.

Discussion of the experiment:

This is suitable both as a class demonstration and as a pupil experiment (5th form upwards). All the observations use uncalibrated values on the screen; accuracy is unimportant since the purpose of the investigation is to observe phenomenological changes and make simple comparisons. Most of the observed effects are due to the temperature dependence of the filament resistance. The experiment can be used to exercise the skills of observation, inference, comparison, design, prediction.

Discussion of the apparatus:

The suggestion here is to construct a single purpose interface box to which may be connected an external battery, rheostat and lamp. The circuit design includes simple protection for the computer inputs against excess and reverse voltages (D1, D2, R4 and R5). This approach minimises errors in making connections to the computer. Alternatively, the circuit could be assembled on the bench in the normal way and connections to the computer made through an 'analogue port extension' such as that supplied by Deltronics. If the latter is used, D1, D2, R4 and R5 are not needed.

The value of R2 is suited to currents up to 0.3A yielding a maximum voltage (V1) of about 0.8V. It is appropriate to restrict V1 to about half of the maximum allowable value of 1.85V so that there is similar precision in the readings obtained for 'current' (V1) and 'voltage' (V2-V1). The actual voltage across the lamp is of course larger than V2-V1 due to the effect of R3. Adjustment of R3 enables larger voltages to be used for the lamp than that suited to the analogue input.

Summary of features:

Example of simple voltage measurements
Uncalibrated values used
Pupil tasks: observation, interpretation, prediction
Software: Results displayed on graph
Main advantages: rapid visual presentation of results
Circuit diagram:

Voltage-Current Relationships
Construction details:

The interface circuit is simply constructed by soldering components on to a stripboard which can be housed in a plastic box fitted with 4mm sockets. Connection to the computer is through a ribbon cable to a 15 way D-type plug which is inserted into the analogue port at the rear of the computer.

Parts list:

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>R2</td>
<td>3R3 2.5W</td>
<td></td>
</tr>
<tr>
<td>R3</td>
<td>10K 0.5W</td>
<td></td>
</tr>
<tr>
<td>R4,R5</td>
<td>4K7 0.25W</td>
<td></td>
</tr>
<tr>
<td>D1,D2</td>
<td>2V7 zener diode</td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>'D' type RS 466-185</td>
<td></td>
</tr>
<tr>
<td>Cover</td>
<td>RS 467-699</td>
<td></td>
</tr>
<tr>
<td>Socket</td>
<td>4mm 4 off</td>
<td></td>
</tr>
<tr>
<td>cable</td>
<td>box</td>
<td></td>
</tr>
</tbody>
</table>

Voltage-Current Interface

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EXPERIMENT 4: HUMIDITY CHANGES

Outline:

Two semiconductor temperature probes are used in simulation of a wet-and-dry bulb hygrometer. The relative humidity of the surroundings is calculated through software and changes are monitored over a period of time.

Apparatus:

- 2 Semiconductor temperature sensors (LM35)
- Analogue port connector (e.g. from Deltronics)
- Muslin wrapping
- Small water container
- Electric fan

![Circuit diagram]

Description:

The two temperature sensors are connected to the analogue port as shown in the circuit diagram. One sensor is wrapped in muslin which is kept moist by dipping in water and both are placed in an artificial draught created by an electric fan. The temperature of each sensor, and of course the temperature difference are monitored and displayed by the software. The relative humidity is also displayed by the software on the basis of these readings. Changes in the relative humidity of the atmosphere can be observed and logged over a period of time, in a greenhouse, in a classroom in a crowded room etc.

Discussion of the experiment:
Discussion of the experiment:

The ideas presented are simply a tool for environmental type investigations into humidity. The unportability of the computer is hardly suited to fieldwork, but for the purpose of collecting data in the field, these particular sensors are very straightforward to use simply with a battery and a voltmeter or a multifunction instrument. The latter is useful for logging data over an extended period of time but the data is best transferred to the computer for the calculation of relative humidity, especially when the amount of data is large. If data-logging is not proposed, it is more sensible to use the traditional method with mercury thermometers.

Discussion of the apparatus and software:

Although a humidity sensor is currently available (e.g. Farnell F2322-691-90001), this experiment has been designed to use two temperature sensors (Farnell LM35CH) which are not only very simple to use but are also likely to find many other applications requiring temperature measurement. It may also be argued that by relating humidity to evaporation, the wet-and-dry principle helps to convey a teaching point about the significance of the relative humidity of the atmosphere.

The LM35 sensor very conveniently gives a low impedance voltage output in direct proportion to the temperature in degrees celsius 10mV/degC. Thus, for example, 250mV indicates 25 degC and the voltage output range is very well suited to the sensitivity of the BBC analogue port. The accuracy of the top grade version of the device is better than that of a mercury thermometer. The accuracy curves published by the manufacturer merit study by older pupils who ought to consider the physical performance and limitations of transducers. For the BBC analogue port, one problem still remains, that of the accuracy of Vref. To overcome this, the voltage reference diode can be used and calibration of the port readings made within the software (See the discussion of Experiment 2).

The humidity is calculated from another look-up table in software. This time, the table is 'two dimensional', requiring two reference values (the dry temperature and the temperature difference) to point to the appropriate humidity value. To understand the principle underlying the method, pupils should be acquainted with the standard hygrometer tables which are published in data books. The computer version should be seen as a profitable use of a computer to store and provide rapid access to numerical information.
Summary of features:

Example of obtaining a derived parameter through software
Simple temperature sensors used requiring no interface
Data is logged over a period of minutes or hours
Pupil tasks: interpretation of graph
Software: Automatically stores data
Uses a look-up table for processing data
Result displayed on graph
Main advantages: Rapid calculation of results
Automatic control of data collection
over long periods

Construction details:

The amount of construction required is trivial. Each LM35 sensor merely requires the attachment of flexible leads and 4mm plugs which enable it to be connected into the analogue port connector. Care must be taken to ensure the electrical insulation of the leads to the sensor when moistened or placed in a liquid. This is conveniently achieved by covering the leads up to the base of the sensor with about 10 cm of heat-shrink sleeving such as RS 397-815.
EXPERIMENT 5: SIMPLE PENDULUM

Outline:

The motion of a simple pendulum is studied by recording its displacement as a function of time continuously for several cycles. The effects of damping on the characteristics of the motion are also observed.

Apparatus:
- servo potentiometer 10K, 0.5% linearity RS 173-580
- stiff wire pendulum with 100g bob
- pieces of card
- analogue port connector

Description:

A high quality potentiometer is used as a transducer for the angular displacement of the pendulum. The potentiometer is connected to the analogue port connector as shown. The potentiometer is clamped so that the wiper subtends the first 60 degrees of the track when the pendulum hangs in the vertical position. The analogue port reading for this vertical position is recorded initially. The pendulum is set into oscillation and the program stores values for the displacement and displays a displacement v.time graph. The software allows the user to pick out the values from different points on the graph, calculate the ratio between two values, and measure gradients at selected points. Using these utilities the user can investigate:
a) the constancy of the period as the amplitude decays.
b) the constancy of the ratio between amplitude values for successive cycles.
c) the relationship between the amplitude and the maximum gradient in a given cycle.
d) the general effect of repeating the experiment with increased damping introduced by attaching pieces of card to the bob.

Discussion of the experiment:

Again, the main emphasis is on the analysis of the data and is most suited to individual or small group activity for 5th formers upwards. There is no point in repeating the traditional investigations into the effect of the length and mass on the period; if used for this, the computer technique is merely depriving pupils in the exercise of manual skills used in the conventional method. Instead, an effort has been made to exploit software techniques for analysing the stored data for properties which are difficult to measure by conventional means i.e. amplitudes, displacements and velocities during the oscillation. Again, the software designer might be tempted to include a routine which could automatically calculate the period and even the acceleration due to gravity. The fact that this is possible in software does not justify its inclusion; the criteria for software design should be determined by those tasks which we want pupils to perform.

Discussion of the apparatus and software:

The type of potentiometer suggested has a conductive plastic track and a multifinger wiper. These features give excellent resolution, repeatability and smoothness of operation. Another important requirement, the linearity, is also of a high order. Unfortunately, at £15, the potentiometer is rather expensive, but the interfacing requirements are minimal. The analogue port connector should contain protection against the input voltage exceeding about 2 volt. The version manufactured by Deltronics is suitable.

The position of the potentiometer in its clamp has been chosen to optimise the range of voltage output for a maximum amplitude of 60 degrees. The software uses the initial port reading for the vertical pendulum to determine subsequent positive and negative displacement values. In order to maximise the response of the measuring system to change, the three unwanted channels are switched off.
Summary of features:

Example of gathering a large amount of data for analysis
Logging data continuously for several seconds
Pupil tasks: observation, interpretation, comparison, analysis of graph
Software: Results both displayed (graph) and stored
                     Redisplay and recall of stored data
                     Calculating aid: gradients
Main advantages: Storage oscilloscope simulated
                     Computer aided analysis of data
                     Easy repetition of experiment with changed conditions
EXPERIMENT 6: MOTION EXPERIMENTS

Outline:

The velocity and acceleration of a trolley on a runway are measured through software using input from an optical sensor. Tests are performed to investigate the relation between force and acceleration.

Apparatus:

- Light activated switch RS 305-434
- Torch lamp and power supply
- User port connector
- Trolley
- Runway
- Pulley in clamp
- String
- Slotted masses 100g - 800g
- Wooden blocks

Description:

The light switch and torch lamp are positioned on each side of the runway so that the passage of the trolley interrupts the light falling on the switch. Within the software, the time of duration of any interruption is recorded. The trolley is fitted with a card having two segments so that the beam is interrupted twice when the trolley passes. The width of each segment and the space between them are typed into the computer. Thus when the
trolley passes through the light beam, two velocities and an acceleration are calculated from the two recorded time measurements. The software sets out the details of the calculation on the screen so that pupils can follow the principles involved. Having set up the apparatus, the first important task is to adjust the slope of the runway to compensate for friction; several tests are made until uniform velocity is produced after the trolley is given a gentle push. Then the trolley is given a series of accelerations using the string and falling masses as shown. For each run, the force used and the acceleration produced are noted manually. Finally pupils would plot a graph manually of acceleration against force.

Discussion of the experiment:

This idea is instantly recognised as a conventional O Level pupils' experiment which is normally fraught with inaccuracy when tickertimers are used. In such circumstances the traditional method is a poor means of gathering evidence for the relationship which is summarised in Newton's Second Law. The computer method, on the other hand, is capable of great accuracy and calls for less skill on the part of the user; it therefore holds out the promise of providing a greater quality of evidence. In essence the computer is functioning as an accelerometer giving direct readings for acceleration. However, great care is needed to make sure that the slickness of obtaining acceleration does not conceal its concept in the mind of the pupil who readily confuses it with velocity. To overcome this danger, the software needs careful design, and the use of the technique needs careful preparation. To these ends the software should reveal all the steps in the calculation for pupils to see. It should be emphasised that the actual measurements are in reality only those of distance and time. As a preliminary, informal use of the light switches should be encouraged so that pupils get a 'feel' for the relation between time and velocity. Then the measurement of two velocities should be understood, their difference, and finally the acceleration.

An interesting extension to the technique described can be produced by replacing the two segment card by one with several segments, each of equal width. It is then possible with suitable software to calculate a succession of velocities and display them as a bar chart or velocity v.time graph.
Discussion of the apparatus and software:

Given a number of precautions, the computer can measure time with great accuracy. For this experiment there are two main points over which care is needed:

a) the response time of the light switch
b) errors in software due to the time needed to execute program operations

The recommended light switch has a very fast response time, and at a reasonable cost it is the most satisfactory device available for timing purposes. It requires an external capacitor and preset variable resistor which are conveniently mounted on the circuit board of the user port connector. This also provides the 5V power supply needed. Being a digital device, with only two output states, it is appropriately connected to the user port of the computer. It is worth noting that this device gives logic 1 when illuminated, which is the opposite of that provided by a light dependent resistor; the difference between the logic produced must be accommodated in the software.

Considering the short duration of the times expected to be measured in this experiment, the software must use a machine code routine in order to achieve accurate timing.

Summary of features:

Example of precision timing and calculation of derived parameters through software
Digital input to computer
Pupil tasks: manipulation of trolley, runway, light gates etc.
observation, interpretation, comparison
Software: Time intervals measured and stored
Recall and display of stored data
Calculation of derived parameters
Main advantages: Simplicity and accuracy of measurements
Easy repetition of experiment with changed conditions
Construction details:

The interface circuit is constructed by soldering components on to a stripboard which can be housed in a plastic box fitted with a DIN socket. Connection to the computer is through a ribbon cable to a 20 way cable mounting socket which is inserted into the user port underneath the computer. The cable only needs to be 6 lines wide and these are inserted into the right hand side of the socket looking into the computer (see diagram). The light activated switch needs flexible leads attached and is conveniently connected to the circuit using a DIN plug.

Parts list:

- Preset: 10K linear
- Capacitor: 22 nF
- Socket: 20 way type RS 469-881 DIN socket 5 way
- Plug: DIN plug 5 way
- Cable: DIN plug 5 way
- Box: 8U PB9
APPENDIX A

SUPPLIERS OF HARDWARE

Educational Electronics
28 Lake Street, Leighton Buzzard Beds.
Range of transducers, interfaces, VELA

Philip Harris
Lynn Lane, Shenstone, Staffs
Range of transducers, interfaces
Suppliers of METER and TIMER interfaces and
Blackboard Electronics modules

Griffin and George
Bishop Meadow Road, Loughborough, Leics. LE11 ORG
Range of transducers, interfaces, GiPSI
Suppliers of MEP Analogue Sensors

Unilab Ltd.
Clarendon Road, Blackburn BB1 9TA
Transducers from Environmental kit
General Purpose Interface for BBC Micro

Research Machines Ltd.
Mill Street, Oxford, OX2 0BW
RM102 Multifunction instrument

W.P.A. Ltd.
The Old Station, Cambridge Road, Linton, Cambs. CB1 6NW
Transducers and interfaces from Environmental kit

RS Components
P.O. Box 253, Corby, Northants NN17 9RS
Sensors, general components

Farnell
Canal Road, Leeds LS12 2TU
Sensors, semiconductors, general components

Deltronics
91 Heol-y-Parc, Cefneithin, Llanelli, Dyfed SA14 7DL
Analogue port connector, CONTROLIT buffer box

Cleveland I-Tec
34 Albert Road, Middlesborough, Cleveland
Temperature sensor interface for VELA
Mounted thermistors
APPENDIX B

SOURCES OF SOFTWARE

Leicester Physics Interfacing Group,
21 University Road, Leicester LE1 7RF
& E.Midlands M.E.P.Regional Centre,
Towers Library, Loughborough University, Leics.
Interfacing programs (Expts.1-5)

MEDUSA,
Bishop Grosseteste College, Newport, Lincoln
Time, velocity and acceleration programs with
expt. notes

Educational Electronics
28 Lake Street, Leighton Buzzard, Beds. LU7 8RX
VELANALYSIS - program for transferring data
from VELA to computer; graphical handling and
analysis

Nelcal Software
Nelson House, Mayfield Road, Walton-on-Thames KT12 5PL
STATPACK - general data handling package

CLEAPSE
Brunel University, Uxbridge UB8 3PH
STORE - data collection with graph display

Philip Harris
Lynn Lane, Shenstone, Staffs. WS14 0EE
DATASTORE - data collection with graph display

Unilab Ltd.
Clarendon Road, Blackburn BB1 9TA
GRAPHER - data collection and analysis
UNICOS - control software

Stainton Hall
Stainton, Kendall. LA8 0LQ
Software for school laboratory expts.

Leeds Department of Education
Computer Development Team, 53 Headingly Lane, Leeds 6
Graphical analysis programs for VELA data

York University Science Education Group
Department of Chemistry, University of York, York Y01 5DD
Programs for capacitor discharge expts. Results
compared with theoretical models.

Cambridge Educational Computing
available from Philip Harris
METER and TIMER programs for use with simple
interfaces.
APPENDIX C

LISTINGS OF DEMONSTRATION PROGRAMS

The following programs illustrate some of the principles described in the text, but in the interests of typing they have been kept as short as possible. A disc of fully developed programs for Experiments 1 to 6 is obtainable from the Leicester Physics Interfacing Group (see Appendix B).

Demonstration Programs for Experiment 1

10 REM THERMISTOR LOOKUP TABLE
20 REM AUTHOR: L.T.Rogers
30 REM This program creates the lookup table for the
40 REM 100K R-T curve matched thermistor
50 REM starting at memory location &A00
60 REM
70 REM Run this program before loading and running
80 REM the Thermistor Decoder program
100 A%=&A00
110 FOR N=0 TO 255
120 READ X
130 A7.7N=X
140 NEXT
200 END
500 DATA &0,&0,&0,&0,&0,&1,&2,&3
510 DATA &3,&4,&5,&5,&6,&6,&7
520 DATA &7,&8,&9,&A,&B,&B,&C
530 DATA &C,&D,&D,&E,&E,&E,&F,
540 DATA &10,&11,&12,&13,&13,&14
550 DATA &15,&16,&16,&17,&17,&18
560 DATA &19,&1A,&1A,&1B,&1B,&1B,
570 DATA &1C,&1D,&1E,&1E,&1F,&1F
580 DATA &21,&21,&22,&22,&23,&24
590 DATA &24,&25,&26,&26,&27,&27,
600 DATA &28,&29,&29,&2A,&2B,&2B,
610 DATA &2D,&2D,&2E,&2E,&2F,&2F,
620 DATA &30,&31,&32,&32,&33,&33,
630 DATA &34,&35,&35,&36,&36,&37,
640 DATA &3B,&3B,&3B,&3B,&3C,
650 DATA &3D,&3D,&3E,&3E,&3F,
660 DATA &40,&41,&42,&43,&44,
670 DATA &45,&45,&47,&47,&48,
680 DATA &49,&4A,&4A,&4B,&4B,
690 DATA &4E,&4F,&50,&50,&51,
700 DATA &53,&53,&54,&54,&55,
710 DATA &57,&58,&59,&5A,&5B,
720 DATA &5D,&5E,&5F,&60,&60,
730 DATA &62,&63,&65,&65,&65,
740 DATA &6B,&6C,&6D,&6E,&6F,
750 DATA &72,&73,&74,&75,&75,
760 DATA &7A,&7B,&7C,&7D,&7E,
770 DATA &82,&83,&84,&85,&86,
780 DATA &8C,&8E,&8E,&8F,
790 DATA &9B,&9A,&9C,&9E,
800 DATA &A7,&A8,&A8,&A9,
810 DATA &B1,&B4,&B7,&B8,
           &C1,&C4,&C8,&CB,
           &CE,&DO,&D2

- 56 -
10 REM THERMISTOR DECODER
20 REM AUTHOR: L.T. Rogers
30 T%=&A00
40 HIMEM=&2E00:I%=&2E00
50 VDU22,7:*FX4,1
60 PROC Colour
70 REPEAT
80 PROC display
90 IFB=71 PROC graph
100 IFB=13 PROC review
110 UNTIL FALSE
120 END
1000 DEF PROC temp
1010 E%=(ADVAL(1)-&3600) DIV&40
1020 temp1=(T%*E%)/2
1030 E%=(ADVAL(2)-&3600) DIV&40
1040 temp2=(T%*E%)/2
1050 ENDPROC
1000 DEF PROC time
1010 PRINTTAB(0,12)CHR$141"Time: "TIME/100" s"
1020 PRINTTAB(0,13)CHR$141"Time: "TIME/100" s"
1030 D%=TIME DIV200;IF TIME MOD200<20I%?D%=(temp1*2):I%?(D%+256)=temp2:PRINTTAB(0,15)" *":ELSEPRINTTAB(0,15)" 
1040 ENDPROC
1000 DEF PROC logon
1010 PROC clear:L%=TRUE;TIME=0
1020 ENDPROC
1000 DEF PROC display
1010 VDU22,7:L%=0:O%=&2010A
1020 PROC options:VDU26
1030 REPEAT
1040 PROC temp
1050 PRINTTAB(0,4)CHR$141"Temperature 1: "temp1" C"
1060 PRINTTAB(0,5)CHR$141"Temperature 1: "temp1" C"
1070 PRINTTAB(12,8)CHR$141"2: "temp2" C"
1080 PRINTTAB(12,9)CHR$141"2: "temp2" C"
1090 IFL% PROC time
1100 PROC off
1110 B=INKEY(0)
1120 IFB=83 PROC logon
1130 UNTILB=13 ORB=71
1140 ENDPROC
1000 DEF PROC options
1100 VDU28,0,24,39,18,30
1110 PRINT$;
1120 PRINT$;"K"$ S "M"$ Start logging"SPC(10)
1130 PRINT$;
1140 PRINT$;"K"$ G "M"$ Graph"
1150 PRINT$;
1160 PRINT$; "K"$"RETURN"M$"Review stored data"
1170 PRINT$;
1180 PRINT$;
1190 ENDPROC
5000 DEFPROC graph
5010 VDU22,1:PROCaxes:PROCgopt
5020 TIME=0
5030 REPEAT
5040 PROC temp: Q%=TIME/50
5050 GCOLO,3:PLOT69,Q%,temp1*8
5060 GCOLO,1: PLOT69,Q%,temp2*8
5070 A=INKEY(0)
5080 UNTIL A=13
5090 ENDPROC
5100 DEFPROC axes
5110 VDU28,0,30,0:PRINT"TEMPERATURE":VDU26
5120 PRINTTAB(20,28)"TIME (s)"
5130 VDU29,100,200;
5140 GCOLO,3:MOVE0,800:DRAW0,0:DRAW1200,0
5150 @7.=3:VDU5
5160 FORX=0 To 1000 STEP 200:PL 0 T 6 9 ,X,-4:MOVEX-48,-24:PRINTX/2:NEXT
5170 FORY=0 To 720 STEP 80:PL0T69,-4,Y:MOVE-96,Y:PRINTY/8:NEXT
5180 VDU4:ENDPROC
5190 DEFPROC gopt
5200 PRINTTAB(0,31)"Press COLO UR 1:PRINT"RETURN ";
5210 COLOUR3: PRINT"for MENU.": ENDPROC
6000 DEFPROC review
6010 @%=4:VDU22,1
6020 PROCaxes
6030 FORX%=100255
6040 GCOLO,3: PLOT69,D%^4,(I%^2+1)^*4
6050 GCOLO,1: PLOT69,D%^4,(I%^2+257)^*4
6060 NEXT
6070 PRINTTAB(0,30)"Press COLO UR1:PRINT"< > ";
6080 COLOUR3: PRINT"to look at values"
6090 PROCgopt:A=GET
6100 PROClook
6110 ENDPROC
7800 DEFPROC clear
7810 FORX%=0 TO511 STEP4: I%=D%=0
7820 NEXT: ENDPROC
8000 DEFPROC look:PROCoff
8010 FORX=0 TO320
8020 MOVEX*4,0: PLOT22,X*4,800
8030 COLOUR3: PRINTTAB(0,0)"Time:"X*2;
8040 PRINTTAB(12,0)"Temp 1:"(I%^X)/2;
8050 COLOUR1: PRINT" Temp 2:"(I%^2+256)/2;
8060 C=GET: IF C=13 X=320
8070 MOVEX*4,0: PLOT22,X*4,800
8080 IF (C=136 ORC=44) ANDX>1:X=X-2
8090 NEXT
8100 ENDPROC
9200 DEFPROC Colour
9210 K$=CHR$133+CHR$157+CHR$131
9220 L$=CHR$156+CHR$135
9230 B$=CHR$132+CHR$157
9240 M$=B$+CHR$135
9250 Y$=CHR$131
9260 ENDPROC
9300 DEFPROC Con:VDU23;11,255;0;0;0:ENDPROC
9310 DEFPROC off:VDU23;11,0;0;0:ENDPROC
Demonstration Program for Experiment 2

10 REM CAPACITOR DISCHARGE
20 REM AUTHOR: L.T. Rogers
30 *FX4,1
40 *FX16,1
50 DIMD%1000
60 @%=4
70 MODE4
80 VDU29,0;80;
100 REM CAPACITOR DISCHARGE
110 PROCscan
120 A=GET;CLS
130 IFA=13PROCreview
140 UNTIL FALSE
2000 DEFPROCscan
3000 DEFPROCreview
4000 DEFPROCdivide
5000 DEFPROCratio
9000 END
1000 DEFPROCscan
1010 CLS
1020 VDU28,0,30,0,10:PRINT"V O L T A G E";VDU26
1030 FORX=0TO1280 STEP4
1040 *FX17,1
1050 IFADVAL%1256=1
1060 Y=ADVAL/64
1070 PLOT69,X,Y
1090 NEXT
1090 PRINTTAB(0,31)"<SPACE> Another scan <RETURN> Review";
1100 ENDPROC
2010 F0RX=0TQ320
2020 PLOT69,X*4,(D7.%X)*4
2030 NEXT
2040 PRINTTAB(0,31)"<SPACE> Another scan <L> Look at values";
2050 B=GET;IFB=76PROClook
2060 ENDPROC
3010 R=0
3020 FORX=0TO320
3040 MOVED%4,70:PLOT22,X*4,960
3050 PRINTTAB(0,30)"Time:"X TAB(20,30)"Voltage:"D%?X;
3060 PRINTTAB(0,31)"< > Browse <R> Ratio </> Divide ";
3070 C=GET;IFC=13 X=320
3080 IFC=82PRCratio;G0TO3050
3090 IFC=47PROCdivide;G0TO3050
3100 MOVED%4,70:PLOT22,X*4,960
3110 IFC=136ANDX>1:X=X-2
3120 NEXT
3130 ENDPROC
4010 R=D%?X
4020 PRINTTAB(0,0)"RATIO: ";R;SPC(20)
4030 ENDPROC
5000 DEFPROCdivide
5010 Q=D%?X;IFQ=0;Q=1E-9
5020 P=R/Q
5030 PRINTTAB(7,0);R"/";Q="P
5040 ENDPROC
Demonstration Program for Experiment 3

10 REM...V-I RELATIONSHIPS
20 REM...AUTHORS: J. SCAIFE & L. ROGERS
50 HIMEM=&3000: VDU22,7
100 *FX16,2
200 PROCColour
210 PROCMaxValues
220 PROCGraph
230 PROCPlot
240 IFA=127: VDU24,4; 4; 1080; 820; : CLG: GOTO230
999 END
1000 DEFPROCMaxValues
1010 J=0: W=0: A3=0: A4=0
1020 VDU22,7: PROCoff
1030 PRINTTAB(5,4)"Set voltage and current to"
1035 PRINTTAB(5)"their maximum values."
1040 PRINTTAB(4)"(Arbitrary units)"
1050 PRINTTAB(7,22)"Then press <SPACE>."
1060 REPEAT
1070 PROCReadPort
1080 PRINTTAB(7,11)D$"Voltage", V
1090 PRINTTAB(7,12)D$"Voltage", V
1100 PRINTTAB(7,15)D$"Current", I
1110 PRINTTAB(7,16)D$"Current", I
1120 REM J=MAX(I), A3=MAX(A1)=MAX VOLTAGE ACROSS R3
1130 REM W=MAX(V), A4=MAX(A2-A1)=MAX VOLTAGE ACROSS R2
1140 IF J<I: J=I
1150 IFA3<A1: A3=A1
1160 IF W<V: W=V
1180 A=INKEY(10)
1190 UNTILA=32
1200 ENDPROC
2000 DEFPLOCGraph
2010 VDU22,1; VDU19,0,4,0,0,0: COLOUR128: CLS
2020 VDU29,180,200; : 6COLO.2
2030 MOVE0,0: DRAW1000,0
2040 MOVE0,800: DRAW0,0: VDU5
2050 FORI=0 TO 1000 STEP 100
2060 MOVEI,0
2070 DRAWI,-20
2080 MOVEI-140,-30: PRINTI/100
2090 NEXT
2100 MOVE0,900
2110 FORI=80 TO 80 STEP 80
2120 MOVE0,I: DRAW-20, I: MOVE-200, I+10: PRINTI/80
2130 NEXT
2140 VDU23,0,10,32,0,0,0,0,0
2150 MOVE400,-65: PRINT"VOLTAGE"
2160 VDU4,28,1,20,1,5: COLOUR2
2170 PRINT"CURREN'T": VDU28,0,31,39,0
2180 PRINTTAB(5,30)"Press "; COLOUR1: PRINT"DELETE";
2190 COLOUR3: PRINT"to wipe."
2200 COLOUR1: PRINTTAB(11,31)" R "; COLOUR2: PRINT"Y ";
2210 COLOUR3: PRINT"or W for colour";
2220 ENDPROC
:000 DEFPROCplot
:010 GCOLO,3
:020 REPEAT
:030 PROCreadport
:040 A=INKEY(0)
:050 PLOT69,(A2-A1)*1000/A4,A1#924/A3
:060 IFA=82 GCOLO,1
:070 IFA=89 GCOLO,2
:080 IFA=87 GCOLO,3
:090 UNTIL A=127
100 ENDPROC
000 DEFPROCreadport
010 *FX17,1
020 A1=ADVAL(1);A2=ADVAL(2)
030 IFA2<A1:A2=A1
040 V=INT((A2-A1)/200)
050 IFA1<0:A1=0
060 I=INT(A1/200)
070 ENDPROC
000 DEFPROCoff:VDU23;11,0;0;0;0:ENDPROC
000 DEFPROCcolour
010 K$=CHR$133+CHR$157+CHR$131
020 L$=CHR$156+CHR$135
030 B$=CHR$132+CHR$157
040 M$=B$+CHR$135
050 Y$=CHR$131
060 C$=CHR$134
070 D$=CHR$141:@%=5
080 ENDPROC
Demonstration Program for Experiment 4

10 REM PENDULUM
20 REM AUTHOR: L.T.Rogers
30 *FX4,1
40 *FX16,1
50 DIMD%1000
60 MODE4
70 PROCsetup
80 REPEAT
90 PROCscan
100 A=GET:CLS
110 IOIFA=13PRQCreview
120 UNTILFALSE
1000 DEFPROCscan
1010 CLS
1020 MOVE0,Z:DRAW1280,Z
1030 FORX=0TO1280STEP4
1040 *FX17,1
1050 REPEATUNTILADVAL0DIV256=1
1060 Y=ADVAL1/F%
1070 PLOT69,X,Y
1080 D%=X/4=Y DIV4
1090 NEXT
1100 PRINTTAB(0,31)<SPACE>another scan<RETURN>Review;
1110 ENDPROC
2000 DEFPRCDreview
2010 MOVE0,Z:DRAW1280,Z
2020 FORX=0TO320
2030 PLOT69,X*4,(D%*X)*4
2040 NEXT
2050 PRINTTAB(0,31)<SPACE>Another scan<L>look at values";
2060 B=GET:IFB=76PROClook
3000 DEFPRLook
3010 R=0
3020 FORX=0TO320
3030 MOVEX*4,70:PLOT22,X*4,960
3040 PRINTTAB(0,30)"Time:"X TAB(20,30)"Displacement:"D%?X-Z DIV4;
3050 PRINTTAB(0,31)< >Browse<R>Ratio<>/>Divide"
3060 C=GET:IFC=13 X=320
3070 IFC=82PROCratio:GOTO3040
3080 IFC=47PROCdivide:GOTO3040
3090 MOVEX*4,70:PLOT22,X*4,960
3100 IFC=136ANDX>1:X=X-2
3110 NEXT
3120 ENDPROC
4000 DEFPRLRatio
4010 R=D%?X-Z DIV4
4020 PRINTTAB(0,0)"RATIO:"R;SPC(20)
4030 ENDPROC
5000 DEFPRLdivide
5010 Q=D%?X-Z DIV4:IFQ=0:Q=1E-9
5020 P=R/Q
5030 PRINTTAB(7,0);R"/";Q="P
5040 ENDPROC
DEFPROC star(K)
  J=0
  VDUS5:GCOL4,0
  REPEAT
  V=ADVAL1
  IF V>J: J=V
  V=V/20
  MOVE V,600:PRINT"*
  A=INKEY(5):MOVE V,600:PRINT"*
  IF V>1280:VDU7
  UNTILA=K
  VDU4
  F%=J/1024
  ENDPROC
DEFPROC setup
  PRINTTAB(0,20) "Allow the pendulum to hang stationary"
  PRINT "in a vertical position."
  PRINT "Adjust potentiometer position in clamp"
  PRINT "until the star is in the centre of the screen."
  PRINT "Then press <SPACE>."
  PROC star(32)
  Z=ADVAL1
  CLS:PRINTTAB(0,20) "Give the pendulum a trial swing."
  PRINT "Then press <RETURN>."
  PROC star(13)
  Z=Z/F%
  ENDPROC
 Demonstration Program for Experiment 5

10 REM WET & DRY BULB HYGROMETER
20 REM AUTHORS: R. Curtis & L.T. Rogers
30 PROC setuptable
40 MODE 7
50 PROC cof f
60 PROC DBL (0,0, "WET AND DRY THERMOMETER")
70 PROC DBL (0,7, "WET")
80 PROC DBL (0,11, "DRY")
90 REPEAT
100 PROC temp (1): W = T
110 PROC DBL (8,7, T$ + " DEGREES CELSIUS ")
120 PROC temp (2): D = T
130 PROC DBL (8,11, T$ + " DEGREES CELSIUS ")
140 IF (D - W) > 10 OR (2*(D - W)) < 1 OR D > 30: PROC DBL (8,15, "CALCULATION IN"
LID ") : GOTO 100
150 RH = HUM (INT (D + 1), INT (2*(D - W)) )
160 PROC DBL (8,15, STR$(RH) + ", " RELATIVE HUMIDITY ")
170 UNTIL FALSE
180 END
1000 DEF PROC temp (C$)
1010 T = 0: FOR I% = 1 TO 100: T = T + ADVAL (C$): NEXT: T = T / 36400
1020 T$ = LEFT$(STR$(T),4)
1030 ENDPROC
2000 DEF PROC DBL (X,Y,W$)
2010 FOR I% = 0 TO 1: PRINTTAB(X,Y+I%):CHR$141; W$: NEXT
2020 ENDPROC
2030 DEF PROC cof f: VDU 23; 11,0; 0; 0; 0: ENDPROC
3000 DEF PROC setuptable
3010 DIM HUM (31,20)
3020 FOR A = 1 TO 31 STEP 2
3030 FOR B = 1 TO 20
3040 READ HUM (A,B)
3050 NEXT: NEXT
3060 FOR A = 2 TO 30 STEP 2
3070 FOR B = 1 TO 20
3080 HUM (A,B) = (HUM (A-1,B) + HUM (A+1,B)) / 2
3090 NEXT: NEXT
3100 ENDPROC
4000 DATA 91,81,73,64,55,46,38,29,21,13,5,0,0,0,0,0,0,0,0,0
4010 DATA 92,84,76,68,61,52,45,37,29,22,14,7,0,0,0,0,0,0,0,0
4020 DATA 93,85,78,71,64,57,49,43,36,29,22,16,9,0,0,0,0,0,0,0
4030 DATA 94,86,80,73,66,60,54,48,41,35,29,24,17,11,5,0,0,0,0
4040 DATA 95,87,81,75,69,63,57,51,46,40,35,30,29,24,19,14,8,0,0,0
4050 DATA 96,88,82,77,71,66,60,55,50,44,39,34,29,24,20,15,10,6,0,0
4060 DATA 95,89,83,78,73,68,63,58,53,48,43,39,34,29,25,21,16,12,8,0
4070 DATA 95,90,85,79,75,70,65,60,56,51,47,42,38,34,30,26,22,18,14
4080 DATA 95,90,85,81,76,71,67,63,58,54,50,46,42,38,34,30,26,23,19
4090 DATA 95,91,86,82,77,73,69,65,61,57,53,49,45,41,38,34,30,27,23
4100 DATA 96,91,87,83,78,74,70,66,63,59,55,51,48,44,41,37,34,31,28
4110 DATA 96,92,87,83,80,76,72,68,64,61,57,54,50,47,44,40,37,34,31
4120 DATA 96,92,88,84,80,77,73,69,66,62,59,56,53,49,46,43,40,37,34
4130 DATA 96,92,88,85,81,78,74,71,67,64,61,58,54,51,49,46,43,40,37
4140 DATA 96,93,89,85,82,78,75,72,69,65,62,59,56,53,51,48,45,42,40
4150 DATA 96,93,89,86,83,79,76,73,70,67,64,61,58,55,52,50,47,44,42,
BIBLIOGRAPHY

1. VELA Sensor Manual  by Andrew Lambert  
   Published by A.S.E., College Lane, Hatfield, Herts  AL10 9AA  
   £2.50  
   Describes a number of circuit designs for transducer interfaces  
   which can be built by teachers or pupils. Veroboard is  
   recommended as the construction medium but the reader has to plan  
   out the board layout for himself.

2. The MEP Analogue Sensor Manual  
   Published by The Romsey Printing Company, Ronsella, Lordswood,  
   Highbridge, Eastleigh, Hants.  SO5 7HR  
   £9.50  
   A broad discussion of different types of sensor together with a  
   range of practical circuit designs for transducer interfaces.  
   Printed circuit board designs are included and the construction  
   and adjustment of each circuit is discussed. The projects are  
   best suited to teachers with some experience of circuit  
   construction.

3. Sunderland File: Interfacing the BBC Microcomputer  
   Published by The Romsey Printing Company  
   £7.00  
   An comprehensive presentation of the principles and practice of  
   interfacing techniques for the BBC Micro, covering both hardware  
   and software considerations.

4. Interfacing - A: Principles  
   - B: Commercial Products  
   - C: Suggestions for Use  
   Published by CLEAPSE School Science Service, Brunel University,  
   Uxbridge UB8 3PH  
   These documents are circulated amongst Members and Associates of  
   CLEAPSE only.  
   In three parts, this guide provides an introduction to the  
   subject of interfacing, a survey of current commercial interfaces  
   and sensors, and a collection of experiments.

5. Transducers for the BBC micro - Information leaflet no.36  
   Using the BBC ports - Information leaflet no.37  
   Published by East Midlands M.E.P., Towers Library, Loughborough  
   University

6. VELA Users' Group newsletters  
   Published by The Physics Department, Leeds University,  
   Leeds LS2 9JT  
   Annual subscription: £2.00  
   Issues contain numerous ideas for applications of sensor  
   technology.
I wrote these programs for the BBC Microcomputer realising that the successful application of the new measurement technology in the classroom depended heavily on quality software for visualising the data as graphs and for performing useful calculations. Each program provided the analysing tools for a particular physical phenomenon. Although conceived as models of suitable software design, the suite of programs acquired a demand from teachers who lacked the time, skills or inclination to write their own data-handling software. Over a period of five years I refined the suite of programs into the ‘Science Measurement Toolkit’ which I licensed to local authorities and sold several hundred copies nationally.
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LEICESTER PHYSICS INTERFACING GROUP

INTERFACING PROGRAMS FOR THE BBC MICRO (Version 3)

This suite of 9 programs for the BBC Microcomputer (Model B or Master) is designed for use with the Leicester Physics Interface Modules. Each program is intended to be used with a particular module connected to the ANALOGUE INPUT PORT of the computer. The modules served by the programs are as follows:

Temperature Module
Capacitor Discharge Module
Current - Voltage Module
Light Switch Module
Analogue Sensors Module

All modules are available from Deltronics, 91 Heol-y-Parc, Cefneithin, Llanelli, Dyfed.

The main design consideration for the software has been to provide pupils with 'tools' for performing analysing tasks on data collected in each experiment. An aim of each program is to give pupils new tasks rather than simply replace their effort in collecting data. In contrast to general-purpose data-collecting software, each program has been tailor-made to the needs and possibilities of each experiment; it is hoped that this feature makes the programs easy to use with the minimum of practice.

The programs:
1. Temperature Measurement (Thermistor sensors)
2. Temperature Measurement (LM35 sensors)
3. Humidity Measurement
4. Capacitor Discharge
5. Current-Voltage Relations
6. Simple Pendulum
7. Time and Speed Measurement
8. Velocity Measurement
9. Acceleration Measurement

General Features:

The main menu of programs is called by inserting the disc in the drive, holding [SHIFT] and pressing and releasing [BREAK].

[ESCAPE] usually restarts a program from its title page.

Most programs offer a screen dump facility for an EPSON-type dot matrix printer.
1. **TEMPERATURE (THERMISTOR SENSORS)**

**Hardware checklist**
- Temperature Measurement Module
- 1, 2 or 3 thermistor probes

**Investigation Suggestions**

1. **Variation of temperature with depth in test tube of hot water.**
   - 2 probes at different depths. Observe cooling curves.
   - Measure and compare gradients.

2. **Test tube of cold water placed in beaker of hot water.**
   - 2 probes to monitor heating and cooling simultaneously.
   - Measure and compare gradients.

3. **Absorption of radiation.** Mains lamp positioned over squares of white paper, black paper, and aluminium foil.
   - 3 probes to monitor rise in temperature of each square.

4. **Miscellaneous experiments on cooling liquids performed in simultaneous pairs, varying parameters such as:**
   - stirring
   - blowing surface
   - mass of liquid
   - surface area of vessel
   - insulation, type and thickness etc.

**Program Notes**

**OPTION 1: LOG DATA**

Temperature values are plotted in real time on a Temperature v. Time graph. Although values are displayed continuously, they are not stored until [S] is pressed.

- [RETURN] Return to Menu and stop logging
- [T] Select timespan
- [R] Select range for temperature axis
- [S] Start logging temperature values
- [COPY] Dump screen image to printer

**OPTION 3: REVIEW STORED DATA**

Plots a graph of values previously logged or stored.

A vertical cursor line is moved using ← → cursor keys.

Pressing [SHIFT] at the same time causes movement in larger steps.

For each position of the cursor the two temperature values and time are shown at the top of the screen.

- [RETURN] Return to Menu
- ← → Browse
- [COPY] Dump screen image to printer
OPTION 4: LOAD DATA

Data previously saved as a disc file may be recalled. [RETURN] after a null entry immediately returns to the main menu.

OPTION 5: SAVE DATA

Collected data for three thermistors is stored as a file on a floppy disc. It is best to use a disc separate from the program disc for this purpose.

OPTION 6: CLEAR DATA

Erases all the currently collected data from the computer memory.

2. TEMPERATURE (LM35 SENSORS)

Hardware checklist

Analogue Sensors Module
1, 2 or 3 thermistor probes

Program Notes

This program follows a similar pattern to that of Program 1, but uses LM35 sensors instead of the thermistors for input via the Analogue Sensors Module. The LM35 offers a greater precision (0.1 degree) than the thermistor.
3. HUMIDITY MEASUREMENT (WET & DRY PRINCIPLE)

Hardware Checklist

Analogue Sensors Module.
2 LM35 temperature sensors (one kept moist using water and muslin; connected to Input 1)
Electric fan for forced convection

Program Notes

On start-up, the temperatures returned by the two sensors are displayed. If their values fall within the limits normally expected for a wet-and-dry bulb hygrometer, the relative humidity is displayed.

LOGGING:
The values of relative humidity are stored at 5 minute intervals for a total period of up to 24 hours.
Press [ESCAPE] to stop logging.
Data can only be cleared by restarting the program from the main disc menu (called by pressing [SHIFT] & [BREAK]).

REVIEW:
Plots a graph of values previously logged or stored.
A vertical cursor line is moved using cursor keys.
Pressing [SHIFT] at the same time causes movement in larger steps.
For each position of the cursor the values of relative humidity and time are shown at the top of the screen.

LOAD DATA:
Data previously saved as a disc file may be recalled.
Pressing [RETURN] after a null entry immediately returns to the main menu.

SAVE DATA:
Collected data for the temperature sensors is stored as a file on a floppy disc. It is best to use a disc separate from the program disc for this purpose.
4. CAPACITOR DISCHARGE

Hardware Checklist
Capacitor Experiment Module
- capacitor (e.g. 50μF)
- resistor (not less than 3k)
- connecting leads

Investigation Suggestions

1. Explore the constant ratio property of the curve:
   i.e. test $\frac{V_0}{V_1} = \frac{V_1}{V_2}$ etc.

2. Find the time constant from the graph and compare this with the calculated value of $RC$.
   Repeat for different values of $R$ and $C$.

3. Calculate the initial charge stored from the area under the curve.
   (Since the vertical axis is voltage and not current, the area must be divided by $R$ to obtain the charge.) Use this for calculating capacitance. $C = \frac{Q}{V}$. Compare with value marked on component.

4. From the graph, tabulate readings of gradients against time and plot a graph of gradient v. voltage.
Program Notes

Values for the voltage on the capacitor are displayed and stored simultaneously. Use the LOOK option to take measurements from the stored data.

Each experiment only takes 8 seconds to run. The program offers numerous opportunities for analysing the graphs.

Press [SPACE] to start the first scan.
  The capacitor is charged up to about 1.8V
  The scan is triggered when the capacitor voltage has fallen to about 1.7V.

Review menu:
  [SPACE] Another scan
  [L] Look at stored values
  [COPY] Dump screen image to printer

LOOK AT VALUES:
A vertical cursor line is moved using ← → cursor keys. Pressing [SHIFT] at the same time causes movement in larger steps.
For each position of the cursor the voltage, time and gradient values are shown at the top of the screen. The gradient values are averaged over 4 stored values on each side of the cursor.

Look menu:
  ← → Browse
  [R] Ratio: store numerator
  [/] Divide: store denominator
  [A] Area
  [RETURN] Replot data
  [COPY] Dump screen image to printer

RATIO:
To calculate the ratio between two voltages at different times:
  1. Position the cursor at the first value. Press [R].
  2. Move cursor to second value. Press [/].
The ratio calculation is then displayed.
Repeat as necessary.

AREA:
Hold down [A] to fill under the curve to the right of the cursor.
3. CURRENT-VOLTAGE RELATIONS

Hardware Checklist
Current-Voltage Module
variable d.c. power supply (e.g. batteries & rheostat)
various torch lamps e.g. 2.5V, 4.5V, 12V in MES holder
(20 ohm carbon resistor, silicon diode, LED)
connecting leads

Connections for torch lamps etc.

Investigation Suggestions
1. Start with the 2.5V lamp. Change the voltage at a steady rate.
   Compare the effect of increasing voltage with decreasing voltage.
   (Change plotting colour to distinguish the points.)
2. Explore the effects of changing the voltage at different rates.
3. Compare characteristics of different lamps. It is useful to
   superimpose the curves on the same axes; do not return to the
   calibration, nor wipe the screen.
4. Compare the effects with the behaviour of a 20 ohm carbon resistor
   or diodes etc.

Program Notes
The initial calibration procedure determines the maximum values on the
axes of the graph. The most interesting results are obtained for
fairly low maximum voltages (connect only one or two dry cells to the
rheostat).
Points are plotted on the graph continuously but none are stored in the computer memory. Different plotting colours may be used to distinguish different curves.

Start up: The maximum current and voltage values to be used are recorded by the computer.

Graph menu 1: Press [SPACE] to start plotting values.

Graph menu 2:

[DELETE] Wipe graph clear
[COPY] Dump screen image to printer
[R] Change plotting colour to red
[Y] ditto yellow
[W] ditto white

The plotting of points occurs continuously but values are not stored by the program. The units of the axes are arbitrary, being scaled according to the maximum values at start-up.

The Current - Voltage Module gives optimum results for load currents up to about 0.3A.

6. SIMPLE PENDULUM

Hardware Checklist
Analogue Sensors Module
Mounted potentiometer 10k connected to Input 1
Rigid pendulum (wire) with 200g bob
Cardboard for damping pendulum motion

Investigation Suggestions

Some graph analysing tasks:

1. Explore the constancy of the period as the amplitude decays.

2. Observe the relationship between velocity and displacement.

3. Use the RATIO calculator to test for exponential decay.

4. Explore the relationship between amplitude and nearest maximum gradient.

5. Explore the effect of damping.
Program Notes

At start-up, rotate the potentiometer in its mount until the star occupies a central position on the screen. Values for the angular displacement are displayed and stored simultaneously. Use the LOOK option to take measurements from the stored data.

The Displacement v. Time graph displays arbitrary units; the plotting of the displacement is scaled to the amplitude of the trial swing. Press [SPACE] to end the scan before complete.

REVIEW: Stored values are replotted
- [SPACE]: Another scan
- [L]: Look at stored values
- [COPY]: Dump screen image to printer
- [V]: Plot values of velocity

LOOK AT VALUES:
- ←: Browse
- [R]: Ratio; store numerator
- [\]: Divide; store denominator
- [A]: Area
- [RETURN]: Review again
- [COPY]: Dump screen image to printer

RATIO:
To calculate the ratio between two displacements at different times:
1. Position the cursor at the first value. Press [R].
2. Move cursor to second value. Press [/].
The ratio calculation is then displayed.
Repeat as necessary

AREA:
Hold down [A] to fill under the curve to the right of the cursor.

7,8 & 9 MOTION EXPERIMENTS

Hardware Checklist
Light Switch Module
1 or 2 light sensors (or light gates)
1 or 2 torch lamps & power supply (for illuminating light sensors)
Segmented cards (see HELP screens in programs)
Dynamics trolley, pulley in clamp, string, plasticine, masses etc.

Investigation Suggestions
The computer is used in much the same way as a scaler-timer; practical arrangements require the light sensor and illuminating lamp to be clamped facing each other so that, when the beam on the sensor is interrupted, the computer will start or stop timing.
1. Maximum speed of a pendulum. Arrange for the bob of a simple pendulum to pass through the beam reaching the light sensor. (Program 7: TIME & SPEED; Option 1) With repeated measurements, the effect of amplitude on the transit time and speed may be investigated.

2. "g" by free-fall. Weight a double segment card with plasticene and drop it through the light beam. (Program 9: ACCELN. Option 1) An interesting variant is to observe the effect of different masses of plasticene.

3. Testing Newton's 2nd Law. Attach a double segment card to a trolley on a runway so that it intercepts the light beam. The trolley may be accelerated using different falling masses attached to the trolley by string over a pulley (see diagram on page 3). (Program 9: ACCELERATION; Option 1)

4. Testing for friction compensation. (Program 8: VELOCITY; Option 2 BAR CHART)

5. Observing uniform & non-uniform acceleration. (Program 8: VELOCITY; Option 2 BAR CHART)

Program Notes

Program 7: Time and Speed
Program 8: Velocity
Program 9: Acceleration

If the light level reaching the sensors falls below a critical level, a signal test screen appears.

During most parts of the program the ESCAPE key allows you to go back to the previous step in the program.

DISTANCE & VELOCITY UNITS OPTIONS:
1. Inputs in cm and calculations in cm/s.
2. Inputs in cm and calculations in m/s.
3. Inputs in m and calculations in m/s.

ACCELERATION CALCULATION OPTIONS:
For Program 9 Options 2 & 3, there is a choice of how the collected data is displayed:
1. Velocities & transit times only. i.e. pupils perform the calculation.
3. Calculation and answer.

The choice of display option is normally set by the teacher when Options 2 or 3 are used for the first time. After this, in order to reset the display option, the Display menu must be recalled by pressing the 0 key when the options for Program 9 are displayed. (There is no screen prompt for obtaining the Display menu.)

Further guidance for setting up and using the programs is given on the HELP screens provided for each program.
Circuit Diagrams

**Thermistors**

Th Curve matched
100K RS 151-243
R 100K 0.5%

**Temperature Sensors**

LM35 RS 317-960

**Capacitor Discharge**

R1 2K7
R2 3K9
D1 IN4002
D2 TSC04BJ RS 283-564
Current-Voltage Relationships

Current-Voltage
R1 11R Rheostat
R2 3R3 7 W
R3 10K 0.5W
R4, R5 1K 0.5W
R6 10K 1k
R7 1K 1k
D1, D2, D3 3V9 Zener

Pendulum
RV 10K servo RS 173-580
R1 47R

Light Switch
R 10K
Tr Phototransistor RS 306-083
IC Hex schmitt 40106
This article describes a range of 'new' methods of performing practical work using the technology of sensors, interfaces and computers. It also argues for careful scrutiny of old and new methods to identify their distinctive contributions to learning science.
The computer-assisted laboratory

L T Rogers

For many pupils the school science laboratory is an exciting place. There may be a number of reasons for this, but I would suggest that the foremost is that it is a place associated with doing practical things, trying experiments and finding things out in a practical way. Whatever the motivating factors for pupils, we as teachers have certain ambitions for pupils' practical work in the laboratory and, although the structure for activity will vary from one lesson to another, the following short list represents the scientific activities that we would hope to find in healthy practical lessons.

# Manipulating apparatus
# Observation
# Asking questions
# Measurement
# Recording data
# Analysing data
# Making inferences
# Sharing/communication of results

One could expand this list to include higher order activities, but for the present discussion it is convenient to focus on these. In this article I aim to discuss how all of these activities can be enhanced using the microcomputer as a practical 'tool' in the laboratory. It is my belief that the microcomputer can give valuable assistance to pupils in acquiring, developing and exercising the skills needed to engage in these activities productively. Most of the discussion will centre around the use of the microcomputer but many of the arguments apply equally to microprocessor-based multifunction instruments such as VELA, GipSi and the RM102.

The micro as a laboratory 'tool'

If we look at what the microcomputer has to offer practical activity in the laboratory, I would argue that it has the potential to

- extend our powers of observations;
- increase the quality of measurement;
- record data in economical and informative ways;
- facilitate interpretation by providing large amounts of high quality information;
- provide calculating and analysing aids for investigating data;
- communicate results to bring out their significance;
- provide motivation through prompt feedback.

Let us first look at the typical hardware needed to realise some of this potential. The microprocessor, as a clock-driven sequential device, is naturally suited to making time measurements under the control of electrical switches and devices such as photodiodes. Hence the microcomputer, with a microprocessor at its core, can be first called upon to function as a timing instrument, through fairly straightforward connections of external switches or photodiodes. The precision of such measurements can, with carefully designed software, be impressive, with a resolution as small as 10 ps.

Secondly, through the connection of an analogue-to-digital converter (adc) circuit the micro can be used as a high impedance voltmeter. A micro which includes such a circuit as a standard feature can readily contribute to practical work, a factor which has rendered the BBC micro a firm favourite in science departments. It is advisable to protect the

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computer against the harmful connection of excessive or negative voltages, but suitable protective interface circuits are neither expensive nor complex (Tebbutt 1986, Brankin and Dunkerton 1986).

Thirdly, through the use of electrical sensors and transducers, the voltage-measuring micro can be used to monitor and measure any physical parameter likely to be encountered in the science laboratory. Much can be achieved with simple and inexpensive sensors (Rogers 1985), but when signal conditioning is needed to make voltages compatible with computer inputs, or if there is a special requirement for versatility or sensitivity, then interface circuits are needed (CET 1984).

Having identified in principle the three main hardware factors, we should explore some of the physical aspects of micro measurement which can enhance practical work. In these, much is due to the microchip circuits which give us the power to collect, store and process information in large quantities and at great speeds. However, hardware is not the only consideration; the role of software in making these features usable, useful and meaningful also emerges as a very important factor.

Observation

The skill of observation in part depends on gathering information, and in this the micro hardware has an obvious role. The ease with which measurements may be repeated brings a new dimension to laboratory work (some may say a rediscovered dimension if one recalls the data memory devices which became available a decade ago). For example, a sequence of readings can now be obtained automatically under software control. This is put to good use when an experiment requires data collection over a period in excess of the normal time allocated to a lesson. For example, a battery under load could be tested to exhaustion, or the humidity and temperature changes in a room during an afternoon could be studied. The timescale for the automatic collection of data can be varied over a considerable range from several days down to milliseconds. This opens up scope for observing a variety of changing phenomena—slow changes, oscillations, short-lived transients or any changing signals which are difficult to record manually. In the time dimension, this aspect of the technology has impressively extended our range of physical perception in the laboratory. Longer term time-dependent phenomena, such as the creep in plastics under load or, at the other extreme, transients such as the current surge when a tungsten lamp is switched on (ASE 1983) are conveniently brought within the scope of science practical work. For transient phenomena, such as this last example, the use of the micro with graphics emulates a storage oscilloscope.

Automatic data collection has a number of other benefits. A sequence of readings is conveniently repeated under different conditions or with different components. For example, displacement–time data for a pendulum could be collected several times over, each with a different amount of friction so that the effect of friction on the decay of the motion might be explored (Crossland 1986). In a different example, the current–voltage characteristics for a number of different electrical devices may be compared (Rogers 1985). In such experiments several sets of results can be gathered in the space of one lesson and the emphasis of the activity is shifted from the analysis of a single set of readings to the comparison of several sets.

In another type of example, automatic data collection frees the pupil to concentrate entirely on manipulating the apparatus; for instance, the current through a tungsten lamp can be shown to be dependent not only on the level of voltage applied but also upon the rate of change of voltage and whether it is increasing or decreasing. By exercising careful manual control over the changing voltage, the effects of thermal 'inertia' may be observed and studied (figure 1).

There are still useful possibilities if we consider software designs which are more restrained than those which produce the automated streams of data collection referred to above, that is, software which permits manual control over the repetition of readings. A suitable example is provided by timing experiments using a photodiode light gate to measure the acceleration of dynamics trolleys under the action of a constant force (Rogers 1985). A single...
key press on the computer is sufficient to initiate another acceleration measurement and, with such ease of repetition, pupils are encouraged to avoid one-off measurements, but instead make a number of exploratory or trial readings and then a series of readings. With liberal repetition, the reliability and repeatability of results can be observed, from which a discussion of the possible sources of error could develop.

Most micro measuring devices offer the means of recording signals on several input channels simultaneously. This is useful in measuring several parameters in an experiment concurrently, especially when time-dependent changes occur at a rate which makes manual recording impossible. The current-voltage investigation of the tungsten lamp referred to above is an example of this. However, another valuable use of this is to run two or more experiments simultaneously, one being used as a control, say, to monitor ambient conditions. Binney (1986) has described an interesting variety of experiments involving the simultaneous use of up to four temperature sensors.

The use of sensors can sometimes extend our ability to observe phenomena in remote, hostile or awkward locations. Since all the sensors likely to be used convert parameters into electrical signals, it is simply a matter of suitable wiring to place a sensor in any desired location, e.g. in dark places, inside machinery, or outside in all weather conditions.

Quality of measurement
There are at least two aspects from which the quality of measurements made with a computer may be assessed. First, there is the physical integrity of the values obtained. Here such questions as the sensitivity, calibration, accuracy and linearity of the sensors and circuits have to be considered. Also, the very detail offered by rapid capture and rapid sampling techniques can be considered to add to the quality of the measurement. Secondly, the usefulness and significance of measurements also contribute to the 'quality' of the measuring process. This second aspect depends much on software methods for processing and communicating data, factors which will be considered later under separate headings.

To take the physical aspect, the micro performs impressively as a timing instrument. As previously indicated, the accuracy and precision of the clock circuits in the micro alone are a great asset. For example, with suitably connected photodiodes, the transit time of a moving vehicle or pendulum bob interrupting light reaching a photodiode can be measured to a theoretical precision of 10μs. (In practice, the accuracy of the measurement is reduced due to the uncertainties in the switching action arising from the finite sensitive area of the photodiode.) In addition, the ability to record a sequence of timed events, such as those involved in collision experiments with two or more vehicles, provides a great advance in the quality of measurement available for investigating momentum (Binney 1986).

Then, as a voltmeter, the micro qualifies admirably, due to the high impedance input of the ADC, which is typically 20 MΩ. This generally enables efficient transfer of a voltage signal to the computer with minimal loss of signal; thus the sensitivity of an input transducer is not degraded. Indeed, it can be enhanced using an operational amplifier, such that, for example, a thermocouple, photodiode, Hall probe or microphone could each yield a response to minute changes in temperature, light, magnetic field or sound respectively.

Recording data
With computer measurement yielding large amounts of data it would be inappropriate for pupils to be tabulating scores of results or indeed pasting print-outs in their lab books. This is best left to the computer itself—the capacity to store information is a key property of the computer. Just as the process of measurement may be automated using the micro, so may the processes of storage and graphical display be performed automatically. Traditionally, the graph is a follow-up activity for extracting meaning from the results. With the computer, the graph takes on a greater importance; it is itself a compact method of storing the data. This method is extremely informative because it puts all the data into context visually; the data can be scanned and searched visually and particular data items can be read out using a roaming cursor. Pupils can systematically select points which they may wish to plot manually. Further software devices—such as windows (figure 2), zoom and auto-scaling—all help

![Figure 2](image-url)
to breathe new life into graphical techniques, creating an exciting and versatile medium for exploring experimental data.

Permanent storage of results is conveniently achieved by saving the data on a floppy disc. This can be useful for lengthy analysis of the data on a subsequent occasion. It could also be used for creating a library of sets of data for a range of different phenomena—but beware that the use of pre-recorded results does not become a substitute for the practical process of gathering experimental data.

**Communicating and interpreting results**

A special strength of computer control of measurement is the variety of software methods available for displaying the data, once gathered. At a very basic level, due to its size, the monitor screen announces measurements in a public manner. Whether the screen display consists of large digits or graphics, the communication of the result is an overtly shared experience. This manner of delivery is ideal both for group work and for stimulating discussion. Also, the promptness of the display is another important aspect in motivating pupils to think about the results. In contrast, for many pupils, the labour of manually plotting a graph so delays the process of appraising the results that their enthusiasm for reaching this stage is likely to wither. Similarly, pupils are encouraged to make predictions if they can be put to the test and their outcome reported promptly. Through promptness and visual techniques software has the potential to accelerate pupils to the level at which they may appreciate the meaning of their results.

Large-digit displays may be suitable for demonstration purposes but are informative in only a limited way; for most of us, analogue representations convey considerably more meaning and generally do so quickly and in a way that commands more interest and attention. Software is particularly good for creating a variety of analogue displays: a bar chart, pie chart, graph, or even a simulated dial display are typical devices for presenting results. All of these readily give a 'feel' for the size of a reading; for example, one can spot at a glance when a value is, say, very small, half full-scale or nearly full-scale. The immediacy of this visual recognition makes the comparison of two or more values shown on the screen simultaneously a very straightforward process. For graphs, the employment of 'windows' on the screen, where several graphs are shown simultaneously (figure 2), is a useful software facility for comparing data. The 'zoom' effect, where a selected portion of a graph is replotted to an expanded scale, is another advantageous facility.

In general, graphs are good for helping us to spot a pattern—a hump or a dip in a curve, symmetry, steepness, displacement, rapid or gradual change are all readily identified visually. Of course, plotting graphs is hardly a new or revolutionary technique! A new factor introduced through computer software is the amount of detail which can be presented in graphical form. Manual graph plotting has typically involved only a relatively small number of data points which represent the useful range of the variables concerned. Such methods have often concentrated on exploring the mathematical relationship between the variables and determining constants from the gradient and intercepts of linear graphs. In contrast, computer-controlled data capture has made it possible to explore a wider range of phenomena which do not conform to neat mathematical expression. This can open up opportunities for problem-solving activities and creative thinking by pupils. With less emphasis on linear graphs, perhaps pupils can cultivate a circumspect and honest attitude towards results where there is less concern for arriving at the right answer and more curiosity towards making sense of the data, recognising similarities, differences, and generally seeking out the significance of data (figure 3).

Comparison of data becomes a convenient and commonplace activity with the aid of computer-generated graphs. A particularly interesting example of this is to compare experimental results directly with the predictions of a theoretical model. Millar and Underwood (Millar and Underwood 1984) have described an experiment in which pupils collect data from a discharging capacitor connected to the analogue port of the BBC micro and compare the voltage–time graph with that produced by a numerical model of decay which is contained in the program. Both theoretical and experimental curves are displayed on the screen simultaneously and

![Figure 3 Cooling curves for two cups of tea. Both cups start at the same temperature. For one cup, the milk is added soon after pouring, while for the other the milk is added after 5 min. The curves clearly show the different rates of cooling](image-url)
pupils can experiment with supplying different parameters to the model until a match is obtained with the experimental results. Through this comparison process pupils can study the accuracy of both the model and the calibration of the capacitor.

All of these possibilities do of course challenge the software designer. Many software packages can be found which have enormous power and flexibility but which also completely baffle the computer-phobic teacher or pupil. User-friendliness is perhaps an overworked piece of jargon, but it remains a crucial factor if most of the benefits described here are to be realised. Designing ‘dedicated’ pieces of software for particular sensors and experiments is one approach which attempts to maximise the emphasis on experimental skill by minimising the computer-operating skill needed. The latter can be achieved by reducing the number of choices within a program to the minimum compatible with the aims of a particular experiment; sampling intervals, duration of logging period, choice of axes, labelling, units and plotting scale can all be preset appropriately (Rogers 1986).

Investigating and analysing data

The micro has numerous applications as a calculating aid. In the context of data-gathering from experiments it is ideal for processing primary data into useful forms. For example, from a set of stored values for voltage and current it is a straightforward matter to generate a set of corresponding values for power or resistance and plot these directly on a graph. There are many such derived quantities which are conveniently calculated from primary measurements. For example velocity, acceleration, force, momentum and kinetic energy may each be calculated from measurements of length, time and mass. In cases when this technique is adopted I think it is important that the program should declare how it uses its primary data so that pupils may be given the opportunity to trace the calculations from first principles. It is often necessary for pupils to work from first principles in order to gain understanding of, say, acceleration and kinetic energy but, when the repetition of these measurements offers new opportunities for learning, I am perfectly happy that the computer should be used as an accelerometer or as an energy meter (Binney 1986).

Derived quantities are frequently obtained from graphs and here software can provide a number of useful aids to pupils in manipulating and analysing data. Chief among these are automatic facilities for interchanging axes, optimising the plotting scale, selecting a false origin and calculating aids for determining features such as gradients, ratios, areas, displacements, average values etc. Figure 4 shows an example of on-screen aids for analysing the collected data for a discharging capacitor. This experiment is quickly performed and conveniently repeated for different resistor and capacitor values, and the main emphasis in pupils’ activity is on the comparison, analysis and interpretation of the data obtained. As in previous examples, given a graph these analyses could be performed manually, but software methods have the distinct advantages of accuracy, speed and ease of repetition and, in use, generally need a lower skill level. It is possible that, for pupils with limited competence in drawings and manipulating graphs, these facilities provide for the first time the means of exercising the higher order skills associated with interpreting graphs. Of course, there is always the danger of software doing too much and pupils too little; it is important that the design of the experiment and the sophistication of the software are balanced so that the activity of the pupil is expanded rather than diminished. Carefully designed software can both expand practical activity and provide useful tools for follow-up activities in which pupils are engaged in an active process of discussing, predicting, interpreting and comparing their results.

Conclusions

The foregoing discussion has indicated some of the expanded opportunities for observation, measurement, communication and analysis of results which are made possible through the use of the micro in practical work. These opportunities deserve to be greeted with enthusiasm, but they should also be
treated with a certain amount of caution. For example, considering the increased range of observation made possible by the micro, it does not necessarily follow that pupils' skills in observation are equally increased. For the exercise of these skills the availability of more information is only one factor to be considered; they depend upon the attention given to the information, the sort of questions being asked when searching information and a discriminating attitude towards the answers. Teachers need to consider these factors when planning the tasks which will be used to cultivate the pupils' skills.

Often, the most appropriate use of computer measurement techniques is in investigating properties which are difficult to measure by conventional means. When using computers we must be careful not to deny pupils the first-hand experience of phenomena; conventional methods are often strong in providing this. The latter also frequently demand the skill of precise measurement, a skill which is virtually eliminated when using a computer-controlled sensor system. The distinctive qualities of computer and conventional methods should be recognised as different but regarded as complementary; the choice of method should match our objectives for the skills to be exercised.

The new tools for observation and measurement—that is sensors, interfaces, the microcomputer and software—themselves require the cultivation of certain skills for their effective use. However, in attending to these we must be careful not to lose sight of the wider responsibility towards the larger amounts of information available; these need discrimination, judgement to be exercised in what is significant, or choices to be made. Perhaps the greatest challenge posed by information technology in general is in learning how to select and reject information. There is no difficulty in gathering and storing large amounts of information; sorting and searching are the attributes which need to be explored. Thus it is in analysing and interpreting data that new advances are possible. Given suitable software 'tools', the micro can reduce the tedium of repetition and enhance pupils' ability to search for significance in experimental results.

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Where to find a C5

Several readers will have been interested to see David Williams' and Colin Terry's article 'The Sinclair C5—physics in action' last November (Phys. Educ. 1986 21 340–3). Unfortunately, the holding company is in receivership. C5s are however still available from Turbine Charm Ltd, costing £299 + VAT. Their address is 49, Allerton Road, Liverpool L18 2DA (tel: 051 722 0909).
In 1988 I designed and built an ultrasonic motion sensor for the BBC Microcomputer having previously seen a similar device demonstrated at a conference in Japan. This article reports on some novel activities with the sensor I had devised for pupils in some local schools.
The Motion Sensor has been developed by Laurence Rogers for use in teaching science, but it also has a lot to offer in connection with the learning of mathematics.

A surprising sensor

At first sight the Motion Sensor simply appears to be a novel device for measuring distance and motion in the school laboratory. However, experience in the classroom shows that it has many surprises in store in providing exciting new opportunities for pupil-centred activity and scientific thinking about the topic of 'motion'.

The past decade has seen an explosion in the number of microelectronic devices and systems coming on to the educational market, many making extravagant claims to transform the teaching of this topic and that concept. Undoubtedly some of the hardware has genuinely succeeded in giving pupils new insights in science but I sense a certain weariness amongst some science teachers for the claims of inventors of microelectronic gadgets. I must declare my own devotion to a practical approach to science, but I must also confess feeling a certain cautiousness about 'gadget-led' education.

However, two years ago, when I first saw a motion detector demonstrated at an international conference, such caution uncontrollably dissolved into enthusiasm for a gadget which promised to liberate pupils from laboratory-bound work on the topic of motion. Here was a range-finding device which could sense and measure the positions and movements of people and objects without the complexity or encumbrance of wires. A year later I had succeeded in making my own Motion Sensor to work with the BBC Micro. When I used it with pupils, I was delighted and surprised to discover that it did much more than open up an exciting new range of practical work; it turns out to be a powerful tool for helping pupils to use all their senses to get a 'feel' of and think about a science topic.

The motion sensor — what it is and how it works

The Motion Sensor in effect provides a sonar ranging system in which the positions and motion of bodies and objects may be monitored. The unit consists of a box of electronics about the size of a tea packet and is connected to the User port of the BBC Micro with a single cable; no other wiring is needed. Under software control the device transmits short pulses of high frequency sound (50 kHz) and detects and amplifies the echoes of nearby objects. Within its 30 degree cone of sensitivity, it has a working range of between 30 cm and 11 metres. The computer is programmed to measure the time interval between transmitted and echo pulses and to calculate the position, velocity and acceleration of the object causing the echo.

Using the device in the classroom

In the classroom the Motion Sensor is positioned on the edge of a bench at about chest height. The computer is positioned such that pupils have a clear vision of the screen as they walk round in front of the sensor. If more than one sensor is to be used in the same room, you have to work out a suitable layout for the room; I have used up to six Motion Sensors with computers in a school laboratory, making sure that neighbouring groups of pupils had enough space without the sonic emissions interfering with each other.

Classroom use of the Motion Sensor is most naturally a group activity. A minimum of two pupils is needed to work the system, but a larger group often generates a more lively exchange of ideas. With 2nd and 3rd years, I prefer to organise pupils in groups of about 4 or 5; this size of group seems to work on its own quite well. The factor which grips pupils' interest is that pupils investigate their own motion; their personal involvement in the experimenting process is intrinsic. This makes a welcome relief from the normal use of stylised laboratory items such as dynamics trolleys, a relief which appears to succeed in attracting more interest amongst girls!

Seeing graphs in 'Real-time'

Through computer software, the data from the echoes detected by the sensor is used to plot distance-time graphs for the motion of the pupil causing the nearest reflections. A graph appears on the screen simultaneously with the pupil's movement so the feedback to the pupils is immediate. In contrast, conventional methods of obtaining graphs for moving objects have always involved manual plotting which inevitably leads to a delay in seeing the pattern in the results. The immediacy of the Motion Sensor's graphs is entirely novel and provides a genuinely interactive experience; pupils can immediately see the effect of their motion on the graph and can respond accordingly. It also gives the graph a new

FEATURE CONTINUED
role; the graph becomes a ‘working medium’ rather than an end product or an object of study. Pupils learn to associate different shapes of graph with different types of movement by actually walking it through themselves. So they learn about the meaning of the graphs through a more comprehensive use of their senses than with conventional deskwork problems. Such a learning process is fundamentally an interactive one, coupling direct physical activity with active thinking, and a fascinating outcome of this is that some of the learning is not of an intellectual kind but is felt in bones and muscles! Through physical experiences pupils can develop a ‘physical intuition’ about graphs which represent features such as getting faster, reversing direction, sudden stops etc.

Once pupils have gained a basic ‘feel’ for the connection between movement and distance-time graphs, a variety of uses of the graphs can follow:

**Predicting and Testing.** One pupil can perform a simple sequence of movements without the use of the sensor, then the rest of the group may predict and sketch on paper the shape of graph they would expect. The predictions can then be tested when the first pupil repeats the sequence with the sensor in use. Alternatively, the screen could first be covered over and the group asked to predict the shape of the graph before removing the cover.

**Matching graphs.** This is an interesting exercise which is often challenging and always good fun. It consists of asking pupils to perform a movement in such a way as to match a graph which is already on the screen. The pre-defined graph may be generated by another pupil or defined by the computer program. Whichever the case, the exercise is truly interactive and provokes a lot of thinking. It is fascinating to watch and listen to pupils trying out this exercise in small groups. Not only does a spirit of competition emerge, but the resulting discussion about the match or mismatch between a pupil’s attempt and a pre-defined graph appears to engender a much clearer personal understanding of graphs. Pupils often learn that it pays to first analyse a graph and plan ahead rather than proceeding by trial and error.

**A qualitative approach.** Most of the activities described so far require very little numerical skill and can give pupils a confident qualitative grasp before tackling a more conceptually demanding quantitative treatment. As a result, it is possible to choose a new starting point for learning about motion; distance-time graphs are feasible as a first encounter and I have been impressed by the confidence of less-able pupils (at the age of 13) in using this graphing tool. When appropriate, a more quantitative treatment, analysing gradients etc. may be used, but the qualitative approaches encouraged by the motion sensor software provide easy access to pupils over a wide range of ability.

**Velocity-time graphs**

When pupils have gained confidence in interpreting the gradients on distance-time graphs, the idea of deriving a velocity-time graph from the distance data can be introduced. Again, pupils can be encouraged to predict the new graph before getting the computer to plot it. Alternatively, why not start with the real-time plotting of velocity graphs? Is it really necessary to start with distance-time graphs? These are some of the interesting questions which I am attempting to explore at the present.

**Designing classroom activity — curriculum materials**

When I first started using the Motion Sensor it seemed to me that there were two important reasons for developing curriculum materials to accompany the dissemination of the device.

First, there is so much to be gained from the use of the sensor if teachers have the confidence to experiment with teaching methods which give pupils a central role in designing and shaping their work. As I have suggested above, much of the learning potential stems from what pupils can do for themselves in an exploratory and investigative mode.

Secondly, an established framework of activities, together with supporting worksheets and guidance material, can help to meet the practical demands of coping in the classroom. Teachers need to respond to the familiar practical issues of how to organise the activity of a class around a limited number of computers, and so on. This requires conceiving a programme of activity which is not wholly dependent on the use of the computer.

To meet these needs, the *Tools for Scientific Thinking Project* at Leicester University is developing written resources for use with the 13–16 age group. The materials comprise Teachers’ notes, Experiment worksheets, Help sheets, and Follow-up problems sheets. The work is funded by MESU who will publish the material later in 1989.

Laurence Rogers

Laurence works at the School of Education at the University of Leicester.

The Motion Sensor (together with software and an instruction booklet) can be obtained (as Item 9200) from Educational Electronics Ltd, 28 Lake St, Leighton Buzzard, Beds LU7 8RX. It costs £60.
'The computer as an aid to practical science - studying motion with a computer'
(with R.Barton) –


The paper describes some novel laboratory activities I had devised using the motion sensor and light gate together with my data-logging software. The value of pupils working in an investigative mode is discussed.
The computer as an aid to practical science—studying motion with a computer

R. Barton & L. Rogers School of Education, Leicester University

Abstract This paper describes the use of two types of physical sensor which enable the microcomputer to be used as a measuring instrument for practical experiments on motion. The systems enable a change of emphasis away from the routine activity of collecting results towards the use of interpreting skills, and are valuable for an investigative style of working in which pupils take a central role in planning and shaping their activity.

Keywords: Practical science; Investigation; Data-logging; Sensors; Motion

Introduction

The past decade has seen an explosion in the number of microelectronic devices and systems appearing on the educational market, many making extravagant claims to transform this or that topic. The ephemeral interest by teachers and pupils in many of these devices suggests that the claims of inventors are too often exaggerated! Nevertheless, some of the hardware has genuinely succeeded in giving pupils new insights in science, and we believe that this is especially so with the Motion Sensor which is already stirring teachers to rethink laboratory activity on the topic of motion. The Motion Sensor is used to sense and measure the positions and movements of people and objects without the complexity or encumberance of wires. Another device, the light gate, although it is no newcomer to the science laboratory, is also making a substantial impact on practical work on this topic. The renewed freshness of activities with this tool arises from coupling it up to the computer; this not only provides precision time measurements for moving objects, but also enables rapid transformation of the measurements into derived quantities such as velocity, acceleration and kinetic energy.

This paper will describe how, in complementary ways, both the motion sensor and light gate can be powerful tools for helping pupils explore and understand their own ideas about motion.

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The Motion Sensor—what it is and how it works

The Motion Sensor in effect provides a sonar ranging system in which the positions and motion of bodies and object may be monitored. The unit consists of a box of electronics about the size of a tea packet and is connected to the User port of the BBC Micro with a single cable; no other wiring is needed. Under software control the device transmits short pulses of high frequency sound (56 kHz) and detects and amplifies the echoes of nearby objects. Within its 30 degree cone of sensitivity, it has a working range of between 30 cm and 11 metres. The computer is programmed to measure the time interval between transmitted and echo pulses and to calculate the position, velocity and acceleration of the object causing the echo.

Using the device in the classroom

In the classroom the Motion Sensor is positioned on the edge of a bench at about chest height. The computer is positioned such that pupils have a clear vision of the screen as they walk around in front of the sensor. If more than one sensor is to be used in the same room, it is necessary to work out a suitable layout for the room; in an average size laboratory up to six Motion Sensors with computers may be comfortably accommodated, making sure that neighbouring groups of pupils have enough space without the sonic emissions interfering with each other.

Classroom use of the Motion Sensor is most naturally a group activity. A minimum of two pupils is needed to work the system, but a larger group often generates a more lively exchange of ideas. With 2nd and 3rd years, a group size of about 4 or 5 pupils seems to work quite well. The factor which grips pupils' interest is that pupils investigate their own motion; their personal involvement in the experimenting process is intrinsic. This makes a welcome relief from the normal use of stylized laboratory items such as dynamics trolleys, a relief which appears to succeed in attracting more interest amongst girls!

Seeing graphs in 'Real-time'

Through computer software, the data from the echoes detected by the sensor is used to plot distance-time graphs for the motion of the pupil causing the nearest reflections. A graph appears on the screen simultaneously with the pupil's movement so the feedback to the pupils is immediate. In contrast, conventional methods of obtaining graphs for moving objects have always involved manual plotting which inevitably leads to a delay in seeing the pattern in the results. The immediacy of the Motion Sensor's graphs is entirely novel and provides a genuinely interactive experience; pupils can immediately see the effect of their motion on the graph and can respond accordingly. It also gives the graph a new role; the graph becomes a 'working medium' rather than an end product or an object of study. Pupils learn to associate different shapes of graph with different types of movement by actually 'walking through the shapes'. So they learn about
the meaning of the graphs through a more comprehensive use of their senses than with conventional deskwork problems. Such a learning process is fundamentally an interactive one, coupling direct physical activity with active thinking, and an interesting outcome of this is that some of the learning is not of an intellectual kind but is felt in bones and muscles! Through physical experiences pupils can develop a 'physical intuition' about graphs which represent features such as getting faster, reversing direction, sudden stops etc.

Once pupils have gained a basic 'feel' for the connection between movement and distance-time graphs, a variety of uses of the graphs can follow:

*Predicting and Testing.* One pupil can perform a simple sequence of movements without the use of the sensor, then the rest of the group may predict and sketch on paper the shape of graph they would expect. The predictions can then be tested when the first pupil repeats the sequence with the sensor in use. Alternatively, the screen could first be covered over and the group asked to predict the shape of the graph before removing the cover.

*Matching graphs.* This is an interesting exercise which is often challenging and always good fun. It consists of asking pupils to perform a movement in such a way as to match a graph which is already on the screen. The pre-defined graph

![Fig. 1. Screen dump of preset graph.](image)

![Fig. 2. Screen dump of graph-matching attempt.](image)
may be generated by another pupil or defined by the computer program. Whichever the case, the exercise is truly interactive and provokes a lot of thinking. It is fascinating to watch and listen to pupils trying out this exercise in small groups. Not only does a spirit of competition emerge, but the resulting discussion about the match or mismatch between a pupil's attempt and a pre-defined graph appears to engender a much clearer personal understanding of graphs. Pupils often learn that it pays to first look carefully at a graph, try to interpret what it means, and plan ahead rather than proceeding by trial and error.

The graphs (Figs 1 & 2) show two different speeds and a stationary period. When attempting a match, pupils soon discover the association between the speed of their movement and the slope of the graph. They also learn how difficult it is to change motion; the stylized sharp corners are impossible to imitate in real life. Pupils further discover how untypical of human movement is the uniform speed represented by the idealized straight lines of the graph: in practice the reciprocating action of their legs shows up as little wobbles on their attempted matching graph. This is particularly noticeable when the derived velocity graph is plotted. (see Fig. 3 below)

A qualitative approach. Most of the activities described so far require very little numerical skill and can give pupils a confident qualitative grasp before tackling a more conceptually demanding quantitative treatment. As a result, it is possible to choose a new starting point for learning about motion: distance-time graphs are feasible as a first encounter and it is interesting to observe the confidence of less-able pupils (at the age of 13) in using this graphing tool. When appropriate, a more quantitative treatment, analysing gradients etc. may be used, but the qualitative approaches encouraged by the motion sensor software provide easy access to pupils over a wide range of ability.

Velocity-time graphs

When pupils have gained confidence in interpreting the gradients on distance-time graphs, the idea of deriving a velocity-time graph from the distance data can

Fig. 3. Screen dump of velocity-time graph superimposed on matching attempt shown in Figure 2.
be introduced. Again, pupils can be encouraged to predict the new graph before using the computer to plot it. As indicated above, the 'wobble' due to leg-action often appears as a total surprise.

Although much of the exciting potential of the motion sensor resides in the pupils exploring their own motion, excellent graphs may be also obtained for wheeled vehicles. Inevitably the intimate connection between the pupil and the subject of investigation is reduced, but as a general rule, smoother graphs are obtained, and this is useful for exploring the more sophisticated ideas associated with velocity and acceleration.

The wheeled vehicle traditionally used in the laboratory for practical work on motion is the dynamics trolley, a robust and versatile device usually dragging behind it a length of ticker-tape to record its motion. Use of the Motion Sensor can completely liberate the trolley from the tangle of ticker-tape, and the computer can present pupils with a clear graph of the motion while it is actually happening. Better still, there is no necessity to confine attention to this type of stylized trolley; the sensitivity of the motion sensor and its 'no-strings' mode of operation enable it to be used with a variety of moving toys. There are several attractions of this; toys, being so familiar to children, readily welcome their interest, and the many different types of mechanical toy provide a variety of different types of motion which may be investigated. For toy cars, the type of motion depends upon the principle employed; inertia, clockwork, triggered springs, or friction.

In the example illustrated in Figure 4, the distance-time graph is displayed while the motion is actually in progress. This is a great advance on the ticker-tape technique which requires time and skill to produce a graph. Here, the graph is available for immediate study and pupils can be encouraged to predict the appearance of the velocity-time graph before instructing the computer to display

![Split-screen dump of s-t, v-t and a-t graphs for a toy car powered by a spring.](image)
it. Similarly, from the v-t graph, pupils may predict the appearance of the acceleration-time graph and then compare their prediction with the a-t graph plotted by the computer. It is difficult for conventional methods to yield all three types of graph for the same example of motion: the Motion Sensor does this with ease and does so with compelling immediacy. This helps to shift the emphasis away from exercising mechanical skills towards investigating and testing ideas. 'How constant is the force of the spring?'. 'How do we know?'. 'What would be the effect on a slope?'. 'How does the motion compare with that of an inertia car?'. These are some of the questions which pupils may be encouraged to ask.

**Light gates— and their use with computers**

Light gates have been used in physics laboratories for many years, although modern light gates use an infra-red source rather than a filament bulb for reliability, and the detector is placed opposite the source of radiation in a single unit to avoid problems of alignment. However, the operation remains the same, if objects pass between the source and detector, a timing device can be used to measure the time radiation is obscured from the detector. In the past, an electronic 'scaler' was used for timing whereas today the light gate can be connected via an interface to a computer. If a card, fixed to a dynamics trolley, passes through the beam, the computer measures the time for the card to pass.

Why go to the trouble of linking a light gate to a computer when other methods have proved so useful for so long? The distance travelled by the trolley in the time interval is the length of the card. Therefore, if the value is entered, the computer can calculate the velocity of the trolley. Using two light gates it is possible to measure both an initial and a final velocity and calculate the acceleration of the trolley. If information on the mass of the object is entered, values of kinetic energy or momentum can be calculated. Perhaps a more important advantage is the use of the screen display available when using a computer? It can provide back-up information and help pupils concentrate on important features. This help can be in the form of giving the appropriate equation to use for a calculation, or the computer itself can perform the calculation but not only display the result but the steps used in the calculation.
Fig. 6. Screen display showing speed calculation.

(Figures 5 & 6). In all cases the data is available as soon as the motion has been completed. Due to the high accuracy of the computer timing, values of velocity and acceleration etc. are subject to much smaller errors than is usually the case using conventional laboratory equipment. Pupils are much more likely to identify patterns and 'discover' relationships if their results are less clouded by errors. Another benefit is the facility to decide on the precision to which the time value is presented, i.e. the number of decimal places displayed, which is particularly useful when working with younger pupils.

Putting the tool to work

The system can be used either to help pupils understand how to measure quantities such as velocity and acceleration, or as a tool to measure quantities directly e.g. as a velocity meter or kinetic energy meter, to allow pupils to explore their own ideas on motion.

In this first role it can be used to help pupils understand how to measure speed. As an alternative to light gates, pupils can measure their running or walking speed by stepping between two pressure pads connected via a suitable module to the computer. The pressure pads act as switches to start and stop the timing. If the separation of the mats is entered, the computer can calculate the pupils speed. The computer is simply acting as a clock and a calculator but as discussed earlier the main benefit is the screen display which shows the equation used and the values of distance and time substituted in the appropriate places. All of this is possible within a few seconds of the motion taking place, helping to form a link between 'the motion', 'the equation' and 'the result'. The computer is ready for the next measurement after a single key press.

'What is the acceleration of a dynamics trolley running freely down a runway?'. This simple question involves three time and one distance measurement. As discussed earlier, the screen display can be used to present the important information in a more understandable form. The pupils still have to perform the calculation themselves but by partially processing the data and
First velocity: 6.89 cm/s
Second velocity: 5.74 cm/s

Acceleration = \frac{\text{velocity change}}{\text{time for change}}

Fig. 7. Information presented to pupils to use to calculate acceleration.

What do pupils think?

It is possible to watch a trolley move past a light gate and have a measurement of its velocity immediately displayed on the screen. This offers exciting possibilities. 'If we double the distance a trolley moves down the slope, by how much will its velocity change?'. By getting pupils to commit themselves to what they expect to happen we are bringing their ideas out into the open. The measured value is displayed as soon as the motion is completed and it is clear if the prediction was incorrect. 'Why was I wrong?'. 'What is the link between speed and distance?'. Again the small measurement errors help the pupil to search for patterns. The method of 'predict and test' is particularly useful when dealing with the factors which affect the acceleration of objects.

For a trolley running down slope:
• 'What happens to the value of acceleration if we push the trolley before it reaches the first light-gate?'
If the trolley is fixed to a falling mass via a length of string:
• 'What is the acceleration after the falling mass hits the floor?'

A fresh look at traditional experiments

Work on Newton’s second law involves the measurement of the acceleration of a trolley for a variety of forces and moving masses. In this case the measurement of acceleration is of secondary importance and so the computer can perform this task freeing the pupil to concentrate on the relationships involved. It is now possible to perform many measurements in a single session not only saving laboratory time but also reducing the time between the investigation and the analysis of the data.
Practical investigations on momentum are also improved using the 'computer method'. Generally, pupils need to measure the momentum of a vehicle before and after various types of collision. The main aim being to verify that momentum is conserved in every case, for all types of collision. It is therefore essential that the pupils are able to investigate as many collisions as possible and that the measurement errors are sufficiently small for the conservation law to be apparent. Using two light-gates, the computer can measure initial and final velocities and calculate momenta, if the mass of each vehicle is entered. After each collision the pupil is presented with a table of values of velocity, momentum and kinetic energy for each vehicle. The focus of the pupils activity then shifts from processing data to evaluating data.

Measurement of the acceleration due to gravity and in particular the effect of mass on its value are in many physics courses. The computer can be used to measure the time for a falling card to reach a measured velocity, making it simple and direct for the pupil to calculate the acceleration. Using the computer as an 'accelerometer' it is a simple matter for pupils to investigate the effect of changing the mass of the falling card. In each case the computer is simply acting as a tool to assist the requirements of the curriculum.

**An investigative approach**

Pupils often enjoy the freedom of exploring their own ideas but the processes of measurement and calculation can easily impede this freedom. With the motion sensor and light gates we have tools which in their different ways enliven and expand the possibilities for investigation available for pupils. Whether the first experience is qualitative using the motion sensor or quantitative with the light gates, both systems offer a fresh approach. With the motion sensor pupils get a feel for the whole motion represented graphically and are able to explore the relationships between distance, velocity and acceleration graphs. With the light gates pupils get a numerical 'snapshot' of the motion which is ideal for exploring the interrelationship between variables. In both cases, the immediate presentation of data connects the investigation and result. This has the effect of freeing pupils to spending most of their time analysing, interpreting and predicting; skills which are at the heart of scientific investigation.

Ultimately, pupils should see these systems simply as some of the tools at their disposal to help perform investigations. Whether this involves the effect of different surfaces on the motion of objects; the effects of shape on the motion of objects; or indeed any other investigation, they should be able to decide that they require say a velocity vs. time graph or a 'kinetic energy meter' and select the most appropriate tool for the job.

**Epilogue**

Much of the learning potential suggested in this paper stems from what pupils can do for themselves in an exploratory and investigative mode. Our experience
Studying motion with a computer

suggests two important aspects which contribute to the success of this approach:

(1) It is necessary to build pupils' confidence rapidly in the 'tools' they are using. This requires both the hardware and software to be easily understood and simple to use. To achieve their purpose as facilitators of science activity, such 'tools' should not preoccupy pupils with the technical skill needed to operate them. Thus, for example, the number of wire connections should be kept to a minimum; screen displays should not be cluttered with unnecessary information; default conditions in the programs should permit the minimum of delay in obtaining and displaying readings.

(2) The software designs should avoid being too prescriptive in their method of use. Flexibility is needed to allow pupils' imagination to flourish. This might be achieved by creating software with an array of diverse facilities but there is a danger that the result turns out to be far from simple to understand and use.

From the design point of view there is a tension between simplicity and flexibility. The examples described in this paper use designs developed at Leicester which have sought to obtain a suitable balance. It is not appropriate here to develop the subject of software design, but in our opinion the importance of this factor should not be underestimated. In particular the very first steps in using software are important for winning the commitment and shaping the attitude of both pupils and teachers.

Forthcoming Conferences

ICCAL'92
4th International Conference on Computers and Learning
Acadia University, Nova Scotia, June 17–20, 1992

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ECER'92
European Conference on Educational Research
University of Twente, Netherlands, June 22–25, 1992

Contact: Prof. dr. Tjeerd Plomp, University of Twente,
PO Box 217, 7500AE Enschede, Netherlands
This paper describes a variety of ways in which computer-based activities can support the ambitions of certain Attainment Targets in the newly published National Curriculum. In particular it suggests how such activities can encourage methods of inquiry implicit in the ‘Exploration of Science’ target.
IT in science in the National Curriculum

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Abstract An investigative and exploratory approach to learning science is emphasised in the National Curriculum. This paper discusses the role of Information Technology in encouraging the methods of inquiry suited to this approach. It illustrates how the use of generic software for data-logging and data handling can permeate a broad range of science topics and fulfill the requirements of the National Curriculum for Information Technology capability.

Keywords: Science; Information technology; Data-logging; Database use

Introduction

Before discussing the role of IT in National Curriculum science it is helpful to consider some of the changes which the introduction of the National Curriculum has brought or is likely to bring to the teaching of science.

First, it is implicit in the orders that all children shall receive a balanced science education up to the age of 16. Hitherto, between the ages of 14 and 16, pupils could study one, two or three separate sciences, usually chosen from the traditional subjects of biology, chemistry and physics. The new programmes of study specify experience spanning all these subjects with the addition of earth science. This move to balanced science was foreshadowed by the 5–16 policy document (DES, 1985) which was largely instrumental in establishing GCSE syllabi in ‘double certificate’ science.

Secondly, the provision of a balanced science curriculum brings opportunities for coherence between the different parts of the curriculum. Whereas the traditional subject divisions have tended to engender different terminology and descriptive systems, the balanced curriculum represented in the programmes of study provides a whole view of the curriculum which encourages teachers to be more aware of the links and interrelations within science.

Thirdly, the programmes of study define a progression and continuity of science experience throughout the years of compulsory education from the age of 5 through to 16. For each attainment target, 10 levels of performance are identified making it possible for teachers working at all levels to be aware of the context of pupils’ previous and subsequent experience in a given topic area. One
significant effect of this has been the clear expectation of an experience of science in primary schools where traditionally the curriculum has contained only a weak provision of science.

Fourthly, the attainment target 'Exploration of science' commends a much more investigative teaching approach in which pupils are encouraged to take more responsibility in the design and evaluation of tasks. Again, this change of emphasis was foreshadowed by the innovations of the GCSE which enhanced the importance of science processes in classwork and assessment.

Fifthly, there is a requirement for assessing and reporting on pupils' performance at four Key Stages corresponding to the ages of 7, 11, 14 and 16. Although assessment mechanisms are still to be published, it is clear that the new reporting system will be much more detailed and will require more frequent testing than those used in the past.

Lastly, the use of Information Technology is explicitly mentioned in the programmes of study. In recent years IT methods have had an increasing influence on teaching and learning science, but the inclusion in the National Curriculum of specific references to IT will accelerate the adoption of IT methods.

The specification of IT requirements in the National Curriculum will be examined next, followed by a more detailed consideration of the implications of IT for the aspects of National Curriculum science described above.

Defining the role of IT in science

Statements relating to the use of IT are to be found under two of the Attainment Targets in Science:

AT1 Exploration of science. 'Pupils should develop the intellectual and practical skills that allow them to explore the world of science and to develop a fuller understanding of scientific phenomena and the procedures of scientific exploration and investigation.'

AT12 The scientific aspects of information technology including micro-electronics. 'Pupils should develop their knowledge and understanding of information transfer and microelectronics.' (DES, 1988).

Also, the National Curriculum Council Consultation Report for Technology (NCC, 1989a) contains one attainment target which identifies aspects of IT capability:

AT5 Information technology capability. 'Pupils should be able to use information technology to:

- communicate and handle information;
- design, develop, explore and evaluate models of real or imaginary situations;
- measure physical quantities and control movement.

They should be able to make informed judgements about the application and importance of information technology, and its effect on the quality of life.'

It is noteworthy that the Consultation Report for Technology promotes the
view that IT should both serve the needs of subjects across the curriculum, and that subject studies should be the vehicle for acquiring and developing IT capability:

'The IT capability will be acquired through a range of subjects rather than through a single subject called information technology.' (NCC, 1989b). A complementary view of IT permeating many areas of the science curriculum was set out in the Consultation Report for Science (DES, 1988): 'The prime importance of IT in science lies in the extent to which its use enhances the skills and knowledge of Science and Technology. . . . this new and powerful tool needs to enrich all the science work for all attainments targets.'

**Information Technology 'tools' for science**

In the case of science there is a particularly good match between the major IT tools and the aspects of IT capability identified above:

1. Data-logging methods for measurement, presentation of results, analysis and interpretation.
2. Spreadsheets for interpreting results and making predictions.
3. Databases for recording, exploring, identifying patterns, interpreting and presenting information.
4. Simulations for investigating, predicting and testing hypotheses.

It will be shown that each of these types of system can make an important contribution to meeting the needs of the attainment targets identified above.

**Data-logging methods**

In the UK there is a strong tradition of practical work as a component of pupils' experience in school science. A notable feature of the Nuffield curriculum developments of the sixties was that they brought fresh vigour and extended the range of practical activity in the school laboratory. More recently, the advent of data-logging facilities has shown the potential for enhancing practical work and creating new opportunities for investigating and thinking about science (Rogers, 1987).

The process of data-logging uses a computer coupled with sensors for physical measurement. Although conventional measurement tasks can be performed with such a system, the most valuable opportunities are realised by exploiting the special facilities which the computer can offer:

- collection of data over very short or very long timespans which are beyond the normal resources of the school laboratory;
  - e.g. for the germination of wheat seeds over several days, or the change in resistance of an electric lamp during the first few milliseconds after being switched on.
- direct measurement of quantities which normally have to be derived by calculation;
  - e.g. velocities, accelerations in mechanics, and electrical resistance, power and energy in electricity.
• prompt and vivid graphical presentation of data in the form of bar charts, and graphs;
• graphical comparison of several sets of data displayed together on the screen;

Graphs have a special role in the contribution which data-logging brings to practical science. In view of the fact that, with the computer, they can be plotted almost simultaneously with the acquisition of data, pupils' first encounter with the data can be graphical rather than numerical. With little effort, pupils can see a pattern or a trend in their results; they can gain an early confidence in using graphs qualitatively before embarking on a more demanding quantitative approach. The promptness and ready availability of graphical display changes the role of the graph in practical investigation. The graph readily becomes a medium for exploratory thinking in which interpreting, analysing, predicting and comparing become the important activities. With a computer, it is no longer appropriate to set pupils a task in which a single graph is the end product; the graph is a starting point rather than an end in itself.

**Spreadsheets**

The world of industry and commerce makes widespread use of spreadsheets for accounting and generally handling numerical data. In school science, whenever measurement is involved, there is potential for the use of this accounting type of software. Although practical work is well served by data-logging techniques, and good quality data-logging software usually provides suitable calculating and analysing aids, spreadsheets can be a useful general purpose tool for storing and analysing experimental data. A spreadsheet is a particularly useful tool when data-logging methods are not the most appropriate for gathering numerical data in practical work. This typically occurs when discrete measurements rather than continuous measurements are involved; measurements of quantities such as volume, mass, distance, and angle etc are usually best served with simple traditional instruments such as rulers, spring balances, and protractors!

A spreadsheet program usually displays a matrix of cells organized in horizontal rows and vertical columns. Pupils may enter a series of numbers for a given variable into a column and use the program to calculate values for a derived variable which can be displayed in another column. (In principle this activity is similar to tabulating a set of results.) The program is very useful for quickly generating data for new variables and for comparing several sets of data to help look for patterns and test relationships. The usual facility for plotting graphs further assists interpreting activities. Depending on the software chosen, spreadsheets may be successfully used by pupils across a range of ability. For example, a child with limited arithmetic skills can use a spreadsheet to begin to look at statistical relationships of data the class has collected, without having to labour over the calculations.
Spreadsheets are used at three main levels of sophistication:

- at the simplest level, a prepared spreadsheet (in which the primary and derived variables are already defined) can be used to sort data and plot a graph of results from a scientific investigation;
- the pupil may design the format of the spreadsheet and define simple mathematical manipulations on the data entered and;
- at the most sophisticated level, the spreadsheet may be used as a tool for modelling.

The data stored in a spreadsheet could be ready collated from standard sources (e.g. standard data for the physical properties of materials) or it could be gathered by the pupils themselves from their own experiments. The method is well suited to collaborative classwork such as conducting a survey.

Databases

In science, databases find numerous applications whenever quantities of data need to be collected, stored, consulted, or sorted. Their use well supports the processes of science such as classification and hypothesis-testing. Both textual and numerical information can be handled using a computer database. The preparation of a database, involving structuring the datafile and collating data, can be an enormously time-consuming task, but not all aspects of the task need to be performed by the user. The methods of using a database can be divided into three levels:

- using a previously prepared datafile: The main activities will revolve around the retrieval of information. This is possibly the simplest mode of use and is well suited to approaches where pupils are responsible for researching information from secondary sources. There exists a good range of commercially available datafiles;
- using an empty datafile but with the structure of field headings already defined: In this mode of use, pupils enter their own data collected from investigations or experiments. They can then analyse the data using the usual range of retrieval techniques;
- the total planning and organization of the structure, collection and retrieval of the datafile by the pupils.

Apart from simply browsing the data contained in a datafile, the commonest activities which involve the retrieval of data are searching, sorting and making graphs. The usual aim of these activities is to stimulate pupils' thinking to give them a better understanding of the data, and to test out ideas about patterns or connections which may exist. Sorting data into alphabetical or numerical order is a useful device for spotting patterns. To make the most effective use of searching facilities, pupils need to develop the skill of formulating the most appropriate questions to ask; then they need to translate the question in terms of the necessary search parameters. As a training ground for developing these
skills, particularly for younger pupils, it is useful to start with special purpose
data handling software devoted to encouraging questioning through sorting and
searching activities. There are some excellent examples based on binary tree
data structures; these are especially valuable in science for providing classifica­
tion activities and the formulation of keys.

Simulations

It is hazardous to make general statements about the type of software which
simulates the behaviour of physical systems or processes. By nature, software
simulations are not general purpose tools like the three considered above; they
are usually designed for a specific purpose on a specific topic. Although
there exists a plentiful number of simulation programs for physical, chemical,
biological and technological systems, many are poorly regarded by teachers and
it is not easy to identify a clear consensus on good quality examples; the regard
for such programs is subject to the teaching styles and personal preferences of
individual teachers. The most derided examples of simulations are those which
simulate physical phenomena which may be readily investigated in a school
science laboratory. In contrast, the most valued examples usually feature
systems which involve complex relationships between many variables, or
systems which are impossible to be replicated in a school due to their expense,
danger, duration, size or inaccessability. The popular examples of a nuclear
reactor and an ecological (pond) system fall into these latter categories.

The most common purpose of using a simulation is to allow the pupil to play
the role of a scientist who can control and vary conditions, predict the
consequences, and study the effects of the variation.

Having reviewed the four principal types of IT which have a special relevance
to science teaching, their contribution to achieving the attainment targets in the
national curriculum will now be examined.

Exploration of science using IT

The character of the Science Attainment target 1 (AT1) 'Exploration of science'
differs from most of the other attainment targets in that it promotes an approach
to learning science rather than defining particular knowledge and understanding.
In a simplified view, AT1 describes the skills and processes which pupils should
experience and develop in science.

'The activities should encourage the ability to:

1 plan, hypothesise and predict;
2 design and carry out investigations;
3 interpret results and findings;
4 draw inferences;
5 communicate exploratory tasks and experiments.'

The Programmes of study set out further aims that 'pupils should relate science
to everyday life, apply their scientific and technological knowledge to a range of problems, and develop skills and attitudes for collaborative working.'

The Non-statutory Guidance (NCC, 1989b) provides a number of examples of starting points for the type of activities which can be used to fulfil the above aims:

- the sorting, grouping and describing of objects and events;
- the observation of similarities and differences between distinctive features and changes over time;
  e.g. comparing the colour, shape and movements of different water animals collected from different parts of a pond;
- designing fair tests for comparing variables;
  e.g. testing toy cars rolling down a slope to compare the effects of steepness and mass;
- surveys: collecting data from within school, in the locality, outside visit, and analysing the data;
- solving a problem posed as a question;
  e.g. 'What makes metals corrode?';
- solving a problem posed as a technological challenge;
  e.g. building a model vehicle, a bridge or a weather station;
- testing out an idea or theoretical model;
  e.g. the link between the reactivity of elements with the structure of the periodic table.

Underlying all the guidance for this attainment target is the spirit of giving pupils a greater measure of responsibility for their activity and learning than has been customary hitherto. Although the detailed statements of attainment contain only a few specific references to methods which use IT, there is considerable consonance between the general ambitions contained in these statements for an investigative style of working and the opportunities offered by IT. IT can offer both an extended range of resources and methods which have excellent potential for encouraging pupils to try out their own ideas and apply their understanding.

- Databases and spreadsheets are powerful tools for investigating data and looking for patterns and relationships;
  In the example quoted above, if the data collected about water animals is entered into a database, searching and sorting activities to find connections between variables are easily invoked. Similar techniques are also well suited to the analysis of data from surveys.
- Prepared databases provide a rich resource of secondary information. There is now generally available a substantial number of datafiles containing collated information for a wide range of topics across the curriculum. Such materials make it easier to provide an 'everyday' context beyond the normal classroom limits.
- Data-logging methods can be good at helping pupils to make good use of data, encouraging them to think about their data and draw conclusions.
For the example of a fair test on toy cars, the computer may be used for timing their movement, but it can also, through software, help pupils use these measurements to obtain values of velocities, accelerations, kinetic energies, and to plot graphs of these quantities.

- Simulations enable pupils to experiment with controlling variables, and testing their predictions.

The Programmes of Study are more explicit about commending the use of these systems across the whole science curriculum: '...pupils should have the opportunity to use information technology to gather and display data from experiments, to simulate physical, biological and chemical systems and their behaviour, to access and organise data relevant to their study of science ...' (DES, 1989).

None of these tools in themselves can guarantee that the objectives of 'Exploring science' will be achieved automatically. They are mere tools, and the manner of their use is crucial in influencing the resultant learning. The responsibility for methodology falls on teachers in the same way as with any other teaching resource. It is possible to use IT tools in a highly structured and directed manner, leaving little scope for pupil initiative, or, in contrast, it is equally possible to allow pupils to make their own decisions on a strategy for investigating data. The success of fulfilling the aims of AT1 is likely to depend as much on the approach of the teacher, as on the use of IT. However, the use of IT should make it easier to give pupils more initiative because IT tools can make certain sophisticated or tedious tasks easier to perform; searching, sorting, measuring, and plotting graphs are activities which require less time and less skill compared with conventional methods. For some teachers it may be a bigger challenge to adapt their teaching style to embrace an investigative approach than to adopt the use of IT. It is clearly important for in-service training to give as much emphasis to teaching strategies as to technical competence in the use of IT. (NCET, 1988).

An ever present constraint on teaching style is the scarcity of resources. Science teachers are well practised in devising practical activity within the limitations of finite supplies of serviceable apparatus and finite time to attend to pupils' practical needs. The fact that practical science is commonly organized as group work probably reflects these constraints, but when, as is often the case, only one computer is available in a laboratory, this organization is really put to the test. Fortunately, using data-logging methods, some experiments can be completed in a short time enabling several groups of pupils to use the equipment on a shift basis. To be effective, this activity needs to be supported by other tasks away from the computer. Whatever the type of software in use, the management of small group activity needs to be carefully planned and organized. Although group work might be instituted for logistical reasons it conveniently provides opportunities for pupils to collaborate on a task. Collaboration is one of the skills which AT1 explicitly aims to encourage. The computer can provide a natural focus for a small group of pupils and provide opportunities for group interactions.
The teaching approach promoted by AT1 applies equally across the whole science curriculum and may be regarded as supporting the aims of obtaining balance and coherence within science. The use of IT further supports these aims, since the same essentially cross-curricular tools may be used for a range of topics spanning biology, chemistry and physics. It is also fortunate that the major IT tools are available at different levels of sophistication so that there can be a smooth progression in the use of IT through different age levels.

Achieving IT capability through science

Reference has been previously made to the statements in the National Curriculum which describe IT capability (NCC, 1989). The main emphasis is on the use of IT as a service tool across the curriculum rather than on an intrinsic study of IT. Throughout the detailed statements in the Programmes of Study there is frequent reference to the use of databases, data-logging, spreadsheets, simulations, wordprocessing and desk-top publishing; tools which all outstandingly serve science teaching. Similarly there is frequent reference to processes which have a central role in science; the collating, storing, retrieving, searching, and sorting of data, the sequencing of instructions, questioning the integrity of data, exploring patterns and relationships, testing hypotheses. Thus, there appear to be plenty of opportunities for the teaching of science and the development of IT capability to be mutually supportive.

Conclusions

The preceding discussion has indicated that there is an impressive variety of opportunities for enhancing the teaching of science through the use of Information Technology. The essence of IT is to give more meaning to the information concerned. Implicitly, it has the potential to bring more understanding in science, but it has been argued that its use also has the potential for encouraging skills and processes which are valued by science teachers and required by the National Curriculum.

References

'A Study of Pupils' Skills of Graphical Interpretation with Reference to the Use of Data-Logging Techniques' -
NATO Advanced seminar (1992) University of Amsterdam.

This paper surveys literature on research into pupils' skills in the use of graphs and describes a number of ways in which graphing software helps pupils overcome common difficulties with graphs.
8. A Study of Pupils' Skills of Graphical Interpretation with Reference to the Use of Data-Logging Techniques

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Abstract. This paper considers the role of graphs in science education and examines the skills required by pupils in interpreting graphs to gain scientific understanding. Some common difficulties in graphical techniques are discussed and the opportunities for overcoming these and for amplifying the value of graphs through the use of the microcomputer are described.

8.1 The Claims Made for Graphs

Graphing is one of the most interesting processes through which hidden patterns may be 'discovered.' Graphs can be made to reveal secret relationships. (Austin et al., 1991, p. 35)

The skills involved in displaying data help pupils to organise their work and communicate their results and ideas to others. (Archenhold, 1988)

The use of graphics for presenting information permeates a wide spectrum of human activity, particularly in science, the media and the world of publishing. Scientists have long used graphs for conveying scientific information, and the ability to read and use information from graphs and charts has been considered essential in science education (Taylor and Swatton, 1990). The prominence and wide use of graphs may be attributed to the view that they provide a versatile language not only for presenting data but for analysing and communicating ideas.

It has been argued (Phillips, 1986) that the graph is a powerful memory aid and thinking aid which helps overcome the limit to the amount of unprocessed information we can memorise or manipulate. A graph effectively processes numerical data into a visual format which not only stores the information but allows it to be referenced as needed. It facilitates parallel processing by the user, enabling the comparison of sets of data which can be coded through movement, colour, brightness, size and shape of symbols. The view of graphs as a language is persuasive when one considers the analogy between items of data and graphs on one hand, and letters, words and sentences on the other: In the language of graphs, the features of the graph in terms of its shape convey ideas about physical change and invoke scientific under-
standing far beyond the scope of columns of numbers which comprise the raw data. These numbers have little significance until they are associated with each other or other data. Graphs provide this association and allow scientists to organise complex experiences into patterns which enrich their understanding (Swan, 1986). In the language of words, words have meaning which transcends the collections of alphabetical letters or phonics of which they comprise; the organisation of words into sentences is able to convey ideas; the exploration of ideas can endow understanding and insight.

Accepting these established claims for the benefits and value of graphs, it will be argued that the value is considerably amplified by the use of the microcomputer which can generate graphs with ease and versatility. In the first instance, microcomputers make graphical presentation available to a wide spectrum of users who lack the skill or time to construct graphs by conventional means, but who nevertheless can take advantage of the insights which graphs can offer. In the school science laboratory, data-logging software makes especially valuable contributions to the quality and scope of practical work. Such software manages the collection, display, storage and analysis of data obtained from physical sensors or data- loggers connected to the computer. In particular, the graphical features of the software enhance pupils' experience and use of the data in the following ways:

• The display of data is immediate.
• Qualitative display precedes quantitative analysis.
• Pupils may work with the data interactively, experimenting with scales and derived data, etc.
• Analysis aids support the process of interpreting graphs.
• Data may be presented in a choice of quality formats.
• A lower skill level is possible, improving access by lower ability pupils.

The significance of these features in helping pupils to acquire skill and overcome common difficulties will be discussed in the context of a survey of the skills associated with creating, manipulating and interpreting graphs.

8.2 Skills Required for Creating and Manipulating Graphs

When pupils are set the task of constructing a graph from their own collected data or from secondary data, they require at least four skills:

• organising the data
• choosing scales
• drawing and labelling axes
• plotting points
These can be taught through drill and practice, and surveys have shown that the majority of 15-year-old pupils can achieve success in these mechanical aspects (Kerslake, 1981, p. 120, and Archenhold, 1988, p. 38). The weakest aspect tends to be in pupils' understanding and use of scale markings. Errors frequently occur when a coordinate does not coincide with a scale marking or grid line, when more judgement is needed for placing a point. The effect of scales on the shape of a graph is a further aspect which reveals weak understanding. Unfortunately the time needed to plot a graph manually does not encourage the pupil to repeat the exercise if an unsuitable choice of scale is made. This is a clear case where the computer can come to the aid of the pupil and offer distinct advantages: Not only is the plotting accurate but, as a result of the speed of computer plotting, graphs may be treated dynamically and interactively; the graph parameters can be changed at will and the control exercised by the pupil takes effect promptly. Computer graphing shows pupils the effect of their decisions without delay, encouraging them to experiment with scales, etc., and generally explore their data. For example, the apparent rate of change of a variable depends upon the choice of scales. The zoom facility in software is a particularly friendly tool for adjusting the magnification and scales to provide a variety of different views of the data.

Of course, allowing the computer to take over the role of plotting the data has the effect of de-skilling the activity from the pupil's point of view, and this could be viewed as a loss. Further, when the computer is used with sensors and data-loggers, the manual skills involved in the collection, tabulation and plotting of data become redundant. However, there are substantial gains to be set against this loss:

- The graph is displayed while the data are being collected so that they are more easily associated with the phenomena they represent.
- Freed from the need to record the data item by item, pupils have more time to observe the phenomena in the experiment.
- The analysis of the graph may become an interactive process, encouraging pupils to test out their ideas about the data and seek their underlying meaning.

The success of the computer in empowering pupils to explore the data depends upon the design of the software giving them confident control over suitable analysing aids. The computer has great potential in shifting an emphasis in pupils' activity away from the gathering of data towards its interpretation.

8.3 Skills Required for Analysing and Interpreting Graphs

The work of Janvier has shown that, as previously noted, whereas most pupils may become proficient at the reading and plotting of graphs, the interpretation of graphs depends on the ability to understand global features such as intervals, maxima and minima, discontinuities and so on. Pupils are much less successful in these areas (Janvier, 1978). Janvier suggests that this could be due to the great emphasis placed by teachers on the 'accurate' skills: choosing scales so that the graph will fit the paper, generating and plotting points, joining them up with a smooth curve, reading
off isolated values, etc. They appear to be emphasised to such an extent that the overall meaning of the graph and the significance of global graphical features are left unexplained in the pupils’ minds. Swan suggests a teaching strategy to help correct the imbalance in this teaching through giving pupils practice in sketching graphs to match descriptions in words or pictures (Swan, 1986). It has been suggested also that the use of the computer can help shift the emphasis in pupils’ activity towards the interpretation of the data. To consider this, the particular skills employed in interpreting graphs will now be surveyed.

There are several levels of sophistication in the process of interpreting graphs. At the simplest level, the graph shape may be viewed qualitatively, identifying trends and interesting features. Progressing to a quantitative treatment, information is obtained from the graph, reading values, performing simple calculations on coordinates and so on. Beyond this, the progression may involve attaching meaning, making generalisations and applying understanding derived from the graph. The following progression will be used in a discussion of interpretation skills:

- Viewing graph qualitatively
- Reading values
- Describing variables
- Relating variables
- Prediction
- Translation

8.3.1 Viewing the Graph

The most obvious feature of a graph is its shape. This can immediately convey information in a qualitative manner without concerning the observer in unnecessary, involved detail. The media and the press make prolific use of the graph as a device for communicating the ‘feel’ for a trend or a relationship. Likewise in science, without any recourse to numerical or quantitative consideration, pupils can gain a glimpse or a quick overview of what may be going on in an experiment; they can ‘see’ gradual or sudden changes, continuity or discontinuity and can select and give attention to particular interesting features. It is a valuable characteristic of data-logging software that the visual representation of the data is the first to be presented to pupils; the numerical attributes can follow when needed. Thus the traditional role of quantitative representation (tabulated results) being the pre-requisite of the qualitative image (graph) can be reversed, allowing pupils to explore the data qualitatively at first.

Such interpretation does not necessarily require axes to be calibrated, but clearly this imposes a limit to the precision of description. Descriptions in simple words can provide valuable stimuli to pupils’ thinking and understanding, but the need for more precise description demands a more quantitative approach. Surveys have shown that children tend to opt for qualitative approaches to investigative practical work (Archenhold, 1988, p. 98) and are disinclined to adopt a more quantitative approach.
which would increase the complexity of the experiment. This reluctance has been identified in pupils even when they have demonstrated competence in constructing graphs in prescribed contexts (Strang, 1990, p. 21). Here, software can support the pupils by reporting initially in a qualitative mode, but then help to develop their ideas about the value of quantitative evidence through a variety of analysing and calculating aids.

8.3.2 Reading Values

Surveys have revealed that pupils tend to find difficulty in reading analogue scales correctly. The interpolation of values between scale markings and an understanding of subdivisions and decimal places are typical casualties. The problem appears to be compounded when two or more readings need to be compared and used to calculate quantities such as gradients and intervals. Using software, reading and calculating data from graphs becomes an almost trivial activity, merely requiring the pupil to manoeuvre a pair of cross hairs to read off values which are displayed in a panel on the screen. This type of facility may be used to gain automatic readouts of coordinates, time intervals, differences, ratios, gradients and areas.

In the traditional context of graphing skills it may seem an abuse to deny pupils opportunities to perform these tasks manually. However, by reducing these skills to a low level, higher order skills can flourish, empowering pupils to think more about the science of their experiment. This has an important impact on investigative and problem-solving approaches to practical science where the problem-solving process relies on service skills such as measurement not requiring thought; they should be effortless and as automatic as possible. The lack of automism interrupts the problem-solving process and can lead to errors (Underwood, 1990, p. 30).

Typically, the reliability of derived data generated by computer calculations is considerably higher than that which depends on pupils’ own arithmetic. This makes the quality of the evidence available to pupils very high. Given that this enhancement makes the pupil better informed, we might hope that their judgements based on the information are also better.

Time dependent data are some of the most common in pupils’ experience of school science. As a variable, time has a special quality; pupils have a natural ‘feel’ for it through a sequence of events or changes in other variables. Sometimes, so strong is the feeling of a schedule of events, pupils tend to interpret data in a ‘pointwise’ fashion rather than in terms of periods of elapsed time; they attach more significance to the time coordinates than the intervals between them (Leinhardt, 1990, p. 37). Software can compensate for this and help strengthen the notion of intervals of time by allowing pupils to choose an arbitrary origin for reading off time measurements. It can also exclude errors in reading the correct number of decimal places for the interval measurement, which often occurs when intervals are less than the interval between consecutive scale markings on the axes. This is similar to the difficulty which pupils experience in interpolating values between the scale markings. Both of these problems are alleviated when the software automatically adjusts the spacing of the
scale markings according to the magnification and uses ‘friendly’ numbers for the scale markings so that interpolation only requires estimates of simple fractions of the scale interval.

Discrete data points on a graph can focus too much attention to the points such that terms like ‘maxima’ and ‘minima’ tend to be confused with the actual height on a graph rather than being identified with the steepness of the graph. Using the computer, data-logging typically involves much larger amounts of collected data plotted more densely on the graph, which helps to disguise the discreteness of the data and emphasise rate of change. Analysing aids make steepness (or gradient) easily computed, and display features can reinforce the concept of rate of change. For example, horizontal and vertical cursor lines may be locked on to the data so that as the pupil controls the movement of one cursor, the other cursor is constrained to follow the data values. The resulting relative movement of the two cursors gives a dynamic and visual indication of the rate at which one variable changes with respect to the other.

Alternatively, the confusion between slope and height might be an example of a linguistic problem in which pupils tend to interpret any words of magnitude casually as ‘big’ or ‘small’ without a clear context of the property being described. To make matters even more complex, this might also be compounded with conceptual difficulties associated with the variables. A common example is the confusion between velocity and acceleration which can cause the words to be used synonymously. Here software can assist by providing opportunities for working interactively with the data; through a range of display, analysing and calculating aids, pupils can readily manipulate their data to probe and test their understanding.

8.3.3 Describing Variables

To describe a variable, pupils need not only obtain information from a graph but also attach meaning to the information. It was noted above that qualitative descriptions may be based on the shape of a graph without any explicit reading of data values. To progress to a quantitative treatment, at least two items of information need to be taken from a graph and then compared in some way. Software analysing aids provide useful assistance in making the types of measurements which benefit such descriptions:

- Maximum, minimum and mean values
- Difference or ratio between two values
- Gradient for rate of change in a variable

The quantity of data contained in a graph naturally lends itself to the study of connections, patterns, and trends in the data. The visual aspect of the graph draws attention to these features more effectively than numbers in columns of tabulated values. Indeed, there is evidence that pupils are distracted from making generalised descriptions by obvious numerical patterns in tabulated results and instead describe patterns such as sequences of odd and even numbers, multiples and differences, etc. (Austin,
Numerical patterns are more difficult to spot when the data are not in serial order but for manual measurements serial data is common since most pupils are trained to increment or decrement the independent variable in an orderly manner. It is unfortunate that tabulated data encourages this type of stepwise analysis which misses the continuity in the behaviour of a variable. Even with a graph, when asked to draw a line through their data, pupils often attempt to join successive points with straight lines, again illustrating this stepwise perception. Software can help to move pupils' thinking towards a continuous view of the data by plotting a best-fit curve which emphasises an underlying trend represented by the shape of the curve.

However, even when pupils focus appropriate attention to the shape of the graph, this does not necessarily result in descriptions of a variable; some pupils instead describe the geometry of the graph line in terms of its shape, direction or curvature in isolation from the axes and from what those axes represent (Austin, 1991, p. 29). A similar geometrical viewpoint is revealed when pupils interpret a graph as the actual picture of a situation; for example, going up and down hills in distance-time graphs (Leinhardt, 1990, p. 39).

Much of this evidence suggests that the process of obtaining scientific descriptions of variables is fraught with distractions; pupils' descriptions are offered at a number of different levels of sophistication. One approach to deflecting attention from numbers, points and geometrical properties is to use software tools for manipulating the data, providing a variety of alternative views and presentations of the data. For example, the data may be smoothed to reduce the effect of 'noise' and emphasise the trend; short-term and longer-term changes may be distinguished; variations in the trend may be observed; the data may be overlaid and compared with a standard mathematical curve; pupils may experiment with matching 'trial fit' curves to their data; differences or 'residuals' between the fitted curve and the data may be plotted (Boohan, 1991, p. 10); scatter graphs indicate a correlation between two variables; or a first derivative (gradient) curve may be plotted. Through a variety of representations, pupils may be encouraged to think about the physical variable rather than the numbers and images which represent it. Software provides quick and convenient tools for all of these manipulations (Rogers, 1992, p. 7). In addition, data-logging in 'real time' helps to forge a link between the physical variable and its graphical representation since the latter appears on the screen simultaneously with the collection of data. The promptness of the display makes an interactive experience possible whereby pupils can alter conditions in an experiment and immediately observe a response (Barton, 1991).

8.3.4 Relating Variables

Identifying and describing a trend or pattern in the behaviour of a variable marks an important stage of sophistication in interpreting graphs because it indicates a perception which is generalized beyond the actual items of data presented on the graph. The majority of graphs generated by data-logging software typically show the time dependence of one or more variables, so the description of a pattern implicitly relates the physical variables to the time variable. Such descriptions are very frequently
concerned with changes, rates of change, growth and decay, which are compound variables which relate a primary variable with time.

Describing the relationship between variables in a generalized manner is the key to developing scientific ideas from the graph, but pupils often find this difficult (Taylor, 1991, p. 15). Sometimes their difficulties are linguistic; they are unsure of the type of expression required; as previously indicated, they may find it easier to use geometrical or numerical descriptions rather than referring to the physical variables. Their terminology may lack precision; the use of vague terms such as "goes up" instead of "increases rapidly" might imply that they are perceiving variables separately and are not consciously relating them. Linguistic considerations may disguise pupils' understanding, but even withstanding this, it is a big step for pupils to see the graph as showing the relationship between two variables (Bell, 1987). Pupils need a teaching strategy which helps them ask appropriate questions and which nurtures and gives them practice in appropriate skills. They also need suitable tools for exploring graphs, tools which are readily provided in software.

The shape of a graph gives vital information about the relationship between the variables. A straight line or a curve have distinctive properties which provide insight and understanding of that relationship.

For a relationship represented by a straight line:

1. Changes in the variables occur at a constant rate.
2. For a given increment in one variable, the other variable always increases or decreases by the same amount. (For the case of a variable plotted against time, the increase or decrease in that variable in a given time interval is always the same.)
3. This is independent of the magnitude of either variable.
4. The ratio between the increases or decreases in either variable is constant.
5. When this ratio is not unity, one variable changes more rapidly than the other.
6. The gradient is the same at all places on the graph, i.e., it is constant.
7. When the gradient is negative, an increase in one variable is accompanied by a decrease in the other.

These descriptions are clearly equivalent to or follow from each other. Their significance is that they are individually testable using software tools: when a cursor is moved across the graph, changes in the variables may be read automatically and the rate of change calculated; measurements may be taken from any selected part of the graph; 'x' and 'y' cursors may be locked together showing easily the relative changes in two variables; the gradient at a cursor may be read automatically.

It is seen that pupils have a variety of ways of exploring the properties of a linear relationship. The same tools and methods may also be used to explore relationships represented by curves:

1. One variable changes more rapidly than the other.
2. The rate of change varies across different parts of the graph.
3. The degree of curvature shows how rapidly the rate varies.

4. Exponential behaviour may be identified when the rate of change varies in direct proportion to the vertical variable.

A further refinement in describing a relationship uses a curve-fitting facility: In a version called 'Trial Fit' (Rogers, 1992) the pupil can choose a general form of mathematical curve and experiment to find out the quality of the fit. The tool is designed so that the pupil is allowed to make a judgement of this quality. The three forms available have been chosen to identify the three most common relationships found in scientific data:

- **Linear**: used for identifying proportionality and extrapolating to find offsets and starting values.
- **Power Law Curves**: used for identifying parabolic, inverse and inverse square relationships.
- **Exponentials**: used for identifying exponential growth or decay.

As in previous examples, the speed of calculation and plotting of data through software provides an interactive tool for pupils. Different types of fit may be tried in rapid succession, and curves may be compared by overlaying so that pupils can look for similarities and differences.

### 8.3.5 Prediction

When a pupil has succeeded in elucidating a generalized relationship between two variables, it will not necessarily indicate that one physically influences the other, but it should make possible interpolation and extrapolation to predict new data values. Thus the successful interpretation can be put to the test by using it to predict new values. Software tools such as best fit curves support pupils in developing confidence in the concept that the description transcends the items of collected data and enables them to identify values between and beyond these items.

Similarly, pupils might predict data and descriptions of the graph shape for new compound variables. For example, predicting a velocity–time graph from a distance–time graph, or a power–voltage graph from a current–voltage graph. Software provides a variety of convenient calculating facilities for generating new data from the collected data allowing pupils to test their predictions.

### 8.3.6 Translation

A further stage of refinement of interpreting skill involves translating the relationship into an algebraic representation. Trends may be classified and described more precisely by association with a mathematical function, but unless the pattern is linear, the manual method of identifying the appropriate function usually depends upon transforming one variable and replotting it in the hope of obtaining
a linear graph. This process can be convoluted, but software offers a number of alternative strategies:

1. The data may be linearised by a suitable function chosen by the pupil.
2. The trial fit technique indicated previously is useful for allowing pupils to interact with the data and use their judgement.
3. Finally, pupils may simulate a function, compare it with the graph of the data and alter the parameters of the function until the best match is obtained.

8.4 Software Design

Effectively designed software gives pupils a large measure of autonomy over the process of collecting and analysing data. The systems offered for control and the appearance of the screen have crucial roles in helping pupils select and exploit what features will be used. If the screen is cluttered with an excess of information, there is a risk that the pupil will be distracted from the purpose of the graph analysis. The 'tool' approach to software is successful when it allows the user to specify which features are to be enabled or hidden and this minimises the number of mandatory decisions when the program is used. However, it is important to give pupils control at a level they can cope with. This requires configuring default conditions so that they can get started easily and build their confidence.

8.5 Teaching and Learning Strategies

This paper has surveyed a range of pupils' difficulties in using graphical techniques and has argued that graphing software and data-logging software both offer significant benefits towards helping pupils overcome these difficulties. However, these software tools and the skills to use them are not enough on their own. Misconceptions cannot be removed by mere 'exposure' to the information contained in graphs. The graph is a thinking aid, but pupils need time to practise describing and using patterns and to engage in the necessary reflection upon their results and discussion with their peers and teacher (Phillips, 1986, p. 42; Taylor, 1991, p. 16). Fortunately, the computer is good at providing time because it performs its tasks so rapidly. It frees pupils to devote more attention to observation, reflection and discussion.

However, it is also necessary for teachers to provide a curricular framework which can challenge pupils with key questions which encourage the type of thinking which goes beyond the simple reading of information from the graph and description of a variable, and leads to an interpretation in terms of a generalised relationship between variables. Teachers also need to review the relative value they attach to different aspects of graphical technique. Pupils' success or failure depends on the incentives to meet targets set by the teacher. Targets implicitly indicate what is valued and important. If the emphasis is to be effectively shifted away from the routine collection and
plotting of data towards the development and use of interpreting skills, the system of rewards and assessment of pupil performance needs to reflect this.

References


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This article proposes a hierarchy of interpretive skills with graphs and describes a series of graph analysis tasks with software which form a progression through the skills.
The computer as an aid for exploring graphs

Laurence T Rogers

Graphs have an important role in conveying scientific information, and the ability to read and use information from graphs and charts is now considered essential in science education. Pupils have more difficulties in using graphical techniques than teachers would like to suppose, especially in interpreting the meaning of graphs and relating physical variables. A new generation of computer software comes to the aid of pupils, not only providing opportunities for overcoming difficulties but also amplifying the value of graphs as tools for scientific investigation.

INTRODUCTION

Data-logging software makes especially valuable contributions to the quality and scope of practical work. It manages the collection, display, storage and analysis of data obtained from physical sensors and data-loggers connected to the computer. Allowing the computer to take on these roles has a profound effect on the skills required by pupils; it renders the manual skills involved in collecting, tabulating and plotting data redundant. For graphs, how much experience of manual plotting do pupils need? Might the traditional emphasis on manual skills impede the interpretation and understanding of graphs? What are the gains when the computer delivers the graph? To discuss these questions, the following observations will be considered for graphs produced by data-logging software.

The display of data can be immediate; the graph can be displayed while the data is being collected so that it is more easily associated with the phenomena it represents.

Qualitative display precedes quantitative analysis; this is less complex than the traditional process which requires the management of numerical data as a pre-requisite of the graphical display which reveals a pattern in the data.

Freed from the need to record the data item by item, pupils have more time to make careful observations of the phenomena in the experiment.

The analysis of the graph may become an 'interactive' process, encouraging pupils to test out their ideas about the data and seek its underlying meaning.

It will be argued that these attributes have great potential in shifting an emphasis in pupils' activity away from the gathering of data towards its interpretation. The computer's success in empowering pupils to explore the data partly depends upon the design of the software giving them confident control over suitable analysing aids. It also makes graphical presentation available to a wide range of users, including the less able, who might lack the skill or time to construct graphs by conventional means, but who nevertheless can take advantage of the insights which graphs can offer.

SKILLS REQUIRED FOR ANALYSING AND INTERPRETING GRAPHS

The work of Janvier has shown that, whereas
most pupils may become proficient at the reading and plotting of graphs, the interpretation of graphs depends on the ability to understand global features such as intervals, maxima and minima, discontinuities and so on. Pupils are much less successful in these areas [1]. Janvier suggests that this could be due to the great emphasis placed by teachers on 'accurate' skills; choosing scales so that the graph will fit the paper, generating and plotting points, joining them up with a smooth curve, reading off isolated values etc. They appear to be emphasized to such an extent that the overall meaning of the graph and the significance of global graphical features are left unexplained in the pupils' minds. Swan suggests a teaching strategy to help correct the imbalance in this teaching through giving pupils practice in rough-sketching graphs to match given descriptions in words or pictures [2]. The activity encourages thinking about the connection between the features of a graph image and their meaning in terms of the physical events they represent. It has been suggested that the use of the computer also succeeds in shifting the emphasis in pupils' activity towards the interpretation of the data. To consider this, the particular skills employed in interpreting graphs will be surveyed.

There are several levels of sophistication in the process of interpretation. At the simplest level, the graph shape may be viewed qualitatively, identifying trends and interesting features. Progressing to a quantitative treatment, information is obtained from the graph, reading values, performing simple calculations on coordinates and so on. Beyond this, the progression may involve attaching meaning, making generalizations and applying understanding derived from the graph. The following progression will be used in a discussion of interpretation skills:

- Viewing graph qualitatively
- Reading values
- Describing variables
- Relating variables
- Making predictions

Translating descriptions into mathematical form

**Viewing the graph**

The most obvious feature of a graph is its shape. Potentially the shape can immediately convey information in a qualitative manner without concerning the observer with unnecessary, involved detail. The media and the press make prolific use of the graph as a device for communicating the 'feel' for a trend or a relationship. Likewise in science, without any recourse to numerical or quantitative consideration, pupils can gain a glimpse or a quick overview of what may be going on in an experiment; they can 'see' gradual or sudden changes, continuity or discontinuity and can select and give attention to particular interesting features. It is a valuable characteristic of data-logging software that the graph can be built up as the experiment proceeds which makes it more easily associated with the phenomena it represents. Also, this visual representation of the data is the first to be presented to pupils; the numerical attributes can follow when needed. Thus the traditional role of quantitative representation (tabulated results) being the pre-requisite of the qualitative image (graph) can be reversed, allowing pupils to explore the data qualitatively at first.

A generally weak aspect of graphwork tends to be in pupils' understanding and use of scale markings. Errors frequently occur when a coordinate does not coincide with a scale marking or grid line, when more judgement is needed for placing a point. The effect of scales on the shape of a graph is a further aspect which reveals weak understanding. Unfortunately the time needed to plot a graph manually does not encourage the pupil to repeat the exercise if an unsuitable choice of scale is made. This is a clear case where the computer can come to the aid of the pupil and offer distinct advantages. Not only is the plotting accurate, but the speed of plotting enables graphs to be treated dynamically without delay, encouraging them to experiment with scales etc and generally explore their data.
For example, the appearance of the rate of change of a variable depends upon the choice of scales. The zoom facility in software is a particularly useful tool for adjusting the magnification and scales to provide a variety of different views of the data (Figure 1).

Interpretation of graph shape does not necessarily require axes to be calibrated, but clearly this imposes a limit to the precision of description. Descriptions in simple words can provide valuable stimuli to pupils' thinking and understanding, but the need for more precise description demands a more quantitative approach. Surveys have shown that, in investigative work, children tend to opt for qualitative approaches to practical work and are disinclined to adopt a more quantitative approach, because of the perceived increase in the complexity of the experiment [3, p 98]. This reluctance has been identified in pupils even when they have demonstrated competence in constructing graphs in prescribed contexts [4, p 21]. Here, software can support the pupils by reporting initially in a qualitative mode, but then helps to develop their ideas about the value of quantitative evidence through a variety of analysing and calculating aids.

Reading values
Surveys have revealed that pupils tend to find difficulty in reading analogue scales correctly [5]. The interpolation of values between scale markings, and an understanding of subdivisions and decimal places are typical casualties. The problem appears to be compounded when two or more readings need to be compared and used to calculate quantities such as gradients and intervals. Using software, reading and calculating data from graphs becomes an almost trivial activity, merely requiring the pupil to manoeuvre a pair of cross hairs to
read off values which are displayed in a panel on the screen. This type of facility may be used to gain automatic readouts of coordinates, time intervals, differences, ratios, gradients, areas, mean values, maxima and minima.

In the traditional context of graphing skills it may seem an abuse to deny pupils opportunities to perform these tasks manually. However, by reducing these skills to a low level, higher order skills may flourish, empowering pupils to think more about the science of their experiment. This has an important impact on investigative and problem-solving approaches to practical science where the problem-solving process relies on service skills such as measurement not requiring thought; they should be effortless and as automatic as possible. The lack of automism interrupts the problem-solving process and can lead to errors [6, p 30].

Typically, the reliability of derived data generated by computer calculations is considerably greater than that which depend on pupils' own arithmetic. Given that this enhancement makes the pupil better informed, we might hope that their judgements based on the information might also be better.

Time dependent data are some of the most common in pupils' experience of school science. As a variable, time has a special quality; pupils have a natural 'feel' for it through a sequence of events or changes in other variables. Sometimes, so strong is the feeling of the schedule of events, pupils tend to interpret data in a 'pointwise' fashion rather than the intervals between them [7, p 37]. Software can compensate for this and help strengthen the notion of intervals of time by allowing pupils to choose an arbitrary origin for reading of time measurements. It can also exclude errors in reading the correct number of decimal places for the interval measurement which often occurs when intervals are less than the interval between consecutive scale markings on the axes. This is similar to the difficulty which pupils experience in interpolating values between the scale markings. Both of these problems are alleviated when the software automatically adjusts the spacing of the scale markings according to the magnification and uses 'friendly' numbers for the scale markings so that interpolation only requires estimates of simple fractions of the scale interval.

Discrete data points on a graph can focus too much attention to the points such that terms like 'maxima' and 'minima' tend to be confused with the actual height on a graph rather than being identified with changes in the steepness of the graph. Using the computer, data logging typically involves much larger amounts of collected data plotted more densely on the graph, which helps to disguise the discreteness of the data and emphasize rate of change. Analysing aids make steepness (or gradient) easily computed and display features can reinforce the concept of rate of change. For example, horizontal and vertical cursor lines may be locked on to the data so that as the pupil controls the movement of one cursor, the other cursor is constrained to follow the data values. The resulting relative movement of the two cursors gives a dynamic and visual indication of the rate at which one variable changes with respect to the other (Figure 2).

The confusion between slope and height might alternatively be an example of lin-
guistic problem in which pupils' tend to interpret any words of magnitude casually as 'big' or 'small' without a clear context of the property being described. To make matters even more complex, this might also be compounded with conceptual difficulties associated with variables. A common example is the confusion between velocity and acceleration which can cause the words to be used synonymously. Here software can assist by providing opportunities for working interactively with the data; through a range of display, analysing and calculating aids, pupils can readily manipulate their data to probe and test their understanding.

Describing variables

To describe a variable, pupils need both to obtain information from a graph and also attach meaning to the information. It was noted above that qualitative descriptions may be based on the shape of a graph without any explicit reading of data values. To progress to a quantitative treatment, at least two items of information need to be taken from a graph and then compared in some way. Software analysing aids provide useful assistance in making the types of measurement which benefit such descriptions:

- Maximum, minimum and mean values
- Difference or ratio between two values
- Gradient for rate of change in a variable

The quantity of data contained in a computer graph naturally lends itself to the study of connections, patterns and trends in the data. The visual aspect of the graph draws attention to these features more effectively than numbers in columns of tabulated values. Indeed, there is evidence that pupils are distracted from making generalized descriptions by obvious numerical patterns in tabulated results and instead described patterns such as sequences of odd and even numbers, multiples and differences etc [8, p 29]. Numerical patterns are more difficult to spot when the data is not in serial order but for manual measurements serial data is common since most pupils are trained to increment or decrement the independent variable in an orderly manner. It is unfortunate that tabulated data encourages this type of stepwise analysis which misses the continuity in the behaviour of a variable. Even with a graph, when asked to draw a line through their data, pupils often attempt to join successive points with straight lines, again illustrating this stepwise perception. Software can help to move pupils' thinking towards a continuous view of the data by plotting a best-fit curve which emphasizes an underlying trend represented by the shape of the curve. However, even when pupils focus appropriate attention to the shape of the graph, this does not necessarily result in descriptions of a variable; some pupils instead describe the geometry of the graph line in terms of its shape, direction or curvature in isolation from the axes and from what those axes represent [8, p 29]. A similar geometrical viewpoint is revealed when pupils interpret a graph as the actual picture of situation; for example, going up and down hills in distance-time graphs [7, p 39].

Much of this evidence suggests that the process of obtaining scientific descriptions of variables is fraught with distractions; pupils' descriptions are offered at a number of different levels of sophistication. One approach to deflecting attention from numbers, points and geometrical properties is to use software tools for manipulating the data, providing a variety of alternative views and presentations of the data. For example the data may be smoothed to reduce the effect of 'noise' and emphasize the trend; short-term and longer-term changes may be distinguished; variations in the trend may be observed; the data may be overlaid and compared with a standard mathematical curve; pupils may experiment with matching 'trial fit' curves to their data; differences or 'residuals' between the fitted curve and the data may be plotted [9, p 10]; scatter graphs indicate a correlation between two variables; a first derivative (Gradient) curve may be plotted. Through a variety of representations, pupils may be encouraged to think about the physical variable rather than the numbers and images which represent it. Software provides quick
and convenient tools for all of these manipulations [10, p 7]. In addition, data-logging in 'real time' helps to forge a link between the physical variable and its graphical representation since the latter appears on the screen simultaneously with the collection of data. The promptness of display makes an interactive experience possible whereby pupils can alter conditions in an experiment and immediately observe a response [11].

Relating variables
Identifying and describing a trend or pattern in the behaviour of a variable marks an important stage of sophistication in interpreting graphs because it indicates a perception which is generalized beyond the actual items of data presented on the graph. The majority of graphs generated by data-logging software typically show the time dependence of one or more variables, so the description of a pattern implicitly relates the physical variables to the time variable. Such descriptions are very frequently concerned with changes, rates of change, growth and decay, which are compound variables relating a primary variable with time.

Describing the relationship between variables in a generalized manner is the key to developing scientific ideas from the graphs, but pupils often find this difficult [12, p 15]. Sometimes their difficulties are linguistic; they are unsure of the type of expression required; as previously indicated, they may find it easier to use geometrical or numerical descriptions rather than referring to the physical variables. Their terminology may lack precision; the use of vague terms such as 'goes up' instead of 'increases rapidly' might imply that they are perceiving variables separately and are not consciously relating them. Linguistic considerations may disguise pupils' understanding, but even withstanding this, it is a big step for pupils to see the graph as showing the relationship between two variables [13]. Pupils need a teaching strategy which helps them ask appropriate questions and which nurtures and gives them practice in appropriate skills. They also need suitable tools for exploring graphs, tools which are readily provided in software.

The shape of a graph gives vital information about the relationship between the variables. A straight line or a curve have distinctive properties which provide insight and understanding of that relationship.

For a relationship represented by a straight line, a variety of statements may be made about its properties.

1 Changes in the variables occur at a constant rate.
2 For a given increment in one variable, the other variable always increases or decreases in equal steps. (For the case of a variable plotted against time, the size of the step for a given time interval is always the same.)
3 This is independent of the magnitude of either variable.
4 The ratio between the increases or decreases in either variables is constant.
5 When this ratio is not unity, one variable changes more rapidly than the other.
6 The gradient is the same at all places on the graph, ie, it is constant.
7 When the gradient is negative, an increase in one variable is accompanied by a decrease in the other.

To the tutored eye, these descriptions are clearly equivalent to or follow from each other. Their significance here is that they are individually testable using software tools: when a cursor is moved across the graph, changes in the variables may be read automatically and the rate of change calculated; measurements may be taken from any selected part of the graph; 'x' and 'y' cursors may be locked together, easily showing the relative changes in two variables; the gradient at a cursor may be read automatically. It can be seen that this provides pupils with a variety of ways of exploring the properties of a linear relationship. The computer tools make these explorations viable and worthwhile, broadening pupils' experience of these properties.

The same tools and methods may also be used to explore relationships represented
Exploring graphs

by curves:

1. One variable changes more rapidly than the other.
2. The rate of change varies across different parts of the graph.
3. The degree of curvature shows how rapidly the rate varies.
4. Exponential behaviour may be identified when the rate of change varies in direct proportion to the vertical variable (Figure 3).

Making predictions

When a pupil has succeeded in elucidating a generalized relationship between two variables, it will not necessarily indicate that one physically influences the other, but it should make possible interpolation and extrapolation to predict new data values. Thus the successful interpretation can be put to the test by using it to predict new values. Software tools such as best fit curves support pupils in developing confidence in the concept that the description transcends the items of collected data and enables them to identify values between and beyond these items.

Similarly, pupils might predict data and description of the graph shape for new compound variables. For example, predicting a velocity-time graph from a distance time graph, or a power-voltage graph from a current-voltage graph. Software provides a variety of convenient calculating facilities for generating new data from the collected data allowing pupils to test their prediction.

Translating description into mathematical forms

A further stage of refinement of interpreting skill involves translating the relationship into an algebraic representation. Trends may be classified and described more precisely by association with a mathematical function, but unless the pattern is linear, the manual method of identifying the appropriate function usually depends upon transforming one variable and replotting it in the hope of obtaining a linear graph. This process can be convoluted, but software offers a number of alternative strategies:

1. The data may be linearized by a suitable function chosen by the pupil.
2. Pupils may simulate a function, compare it with the graph of the data and alter the parameters of the function until the best match is obtained.
3. Curve-fitting techniques.

Software curve-fitting facilities generates very attractive smooth curves, but often their mathematical description consists of complex polynomials expressions. In a version called 'Trial Fit' [10] the pupil can choose a simple general form of mathematical curve and experiment to find out the quality of the fit. The tool is designed so
**Exploring graphs**

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Straight line fit: \( y = ax + b \)
- where \( a = 8.8828 \)
- \( b = 300 \)

 曲线拟合: \( y = ax^2 + b \)
- where \( a = 8 \)
- \( b = -1 \)

**Figure 4**  ‘Trial Fit’ curve fitting: pupils may experiment to find out which type of curve most appropriately describes the experimental data.

that the pupil is allowed to make a judgement of this quality. The virtue of restricting the choice to three simple forms is that pupils might readily associate them with simple numerical descriptions. The three forms available have been chosen to identify the most common relationships found in scientific data:

- **Linear**  Used for identifying proportionality, and extrapolating to find offsets and starting values.
- **Power Law curves**  Used for identifying parabolic, inverse and inverse square relationships.
- **Exponentials**  Used for identifying exponential growth or decay.

As in previous examples, the speed of calculation and plotting of data through software provides an interactive tool for pupils. Different types of fit may be tried in rapid succession, and curves may be compared by overlaying so that pupils can look for similarities and differences (Figure 4).

**SOFTWARE DESIGN**

Effectively designed software gives pupils a large measure of autonomy over the process of collecting and analysing data. The systems offered for control and the appearances of the screen have crucial roles in helping pupils select and exploit what features will be used. If the screen is cluttered with an excess of information, there is a risk that the pupil will be distracted from the purpose of the graph analysis. The ‘tool’ approach (content-independent) to software is successful when it allows the user to specify which features are to be enabled or hidden and this minimizes the number of mandatory decisions when the program is used. However, it is important to give pupils control at a level they can cope with. This requires configuring default conditions so that they can get started easily and build their confidence.
TEACHING AND LEARNING STRATEGIES

This article has surveyed a range of pupils' difficulties in using graphical techniques and has argued that graphing software and data-logging software offer significant benefits towards helping pupils overcome these difficulties. However, these software tools and the skills to use them are not enough on their own. Misconceptions cannot be removed by mere 'exposure' to the information contained in graphs. The graph is a thinking aid, but pupils need time to practise describing and using patterns to engage in the necessary reflection upon their results and discussion with their peers and teacher [14, p 42; 12, p 16]. Fortunately, the computer is good at providing time because it performs its tasks so rapidly. It frees pupils to devote more attention to observation, reflection and discussion [15].

It is also necessary for teachers to challenge pupils with key questions which encourage the type of thinking that goes beyond the simple reading of information from the graph and description of a variable, and leads to an interpretation in terms of a generalized relationship between variables. The graph should be considered as a resource and starting point for thinking activity rather than an end point of lesson activity. It also requires vision of methods for exploiting software; methods for comparing data, using cursors, performing calculations, fitting curves, altering scales etc.

Finally, teachers need to review the relative value they attach to different aspects of graphical technique. Pupils' success or failure depends on the incentives to meet targets set by the teacher. Targets implicitly indicate what is valued and important. If the emphasis is to be effectively shifted away from the routine collection and plotting of data towards the development and use of interpreting skills, the system of rewards and assessment of pupil performance needs to reflect this.

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This article follows on from Portfolio item 8, and describes strategies for designing tasks employing the software tools for analysing graphs.
New data-logging tools – new investigations

Laurence Rogers

The chief value of data-logging to practical science resides not in the process of automated data-gathering but in the processes of analysing and interpreting the data.

Of the information-handling technologies, data-logging has a special role in science, providing a valuable range of tools for 'hands-on' experience in the school laboratory.

At face value data-logging is merely an electronic method of gathering and recording physical measurements; electrical sensors provide signals which are calibrated and recorded by a computer system. However, the chief value of data-logging to practical science resides not in the process of automated data-gathering but in the processes of analysing and interpreting the data. Some of the software tools and methods for exploring graphical data on a computer have been described previously (Rogers, 1995). This article will illustrate how the context for this sort of activity can be set in investigations and consider some of the decisions the teacher has to make when designing the activity.

The benefits of data-logging

In designing the tasks and framing the context for data-logging it is necessary to have a clear vision of the expected benefits. The distinction between the properties and potential benefits of data-logging has been discussed elsewhere (Rogers and Wild, 1996). Properties are not benefits; they have to be turned into benefits by suitable application. For example, one property of data-logging is to provide 'real-time' reporting where the measurements are presented on the screen continuously while the investigation is in progress. This has no benefit if pupils passively watch the computer gathering the data; indeed this situation disinterests pupils (Newton, 1997). The benefit comes from making immediate observations of the data, asking questions about them, looking for links with other information, making comparisons, making predictions, looking for trends, and so on. In short, the benefits depend upon the quality of the thinking about the data. Teachers are skilled in prompting pupils to think. Here is an important context for exercising this skill which has been highlighted in Barton's studies of pupils' interpretation of graphs presented with software (Barton, 1997).

Designing a data-logging activity

With data-logging, the graph is a starting point for thinking. The graph need no longer be regarded as the end-product of an investigation as often occurs in conventional practice. It is important to recognise the implications of this for the design of classroom activity; it provides new opportunities but also new challenges.

As with any classroom activity, having chosen the curriculum topic to be served, the starting point for planning must be to identify the purpose of the task in terms of the anticipated learning outcomes. The task will involve posing questions which point the way to such outcomes and using the software tools to find answers. Pupils need purposeful strategies for selecting...
New data-logging tools

Rogers

Questions

Learning outcomes

Strategies

Software tools

Figure 1

Factors that contribute to the design of data-logging tasks

and using the tools and this requires both confidence in using the tools and vision of the useful information that can be obtained through their use. Figure 1 highlights the main factors that contribute to the design of a task.

The learning outcomes appropriate to a task clearly depend on the context but the following are some suggested general objectives:

- be able to use a graph to describe events in an investigation;
- be able to make connections between observations and graph shape;
- have knowledge of variables which affect each other;
- describe patterns and relationships between variables;
- be aware of the properties of linear relationships;
- interpret data in terms of previously learned theories;
- understand how theories can be tested by looking at data;
- make predictions from collected data.

These should be achievable through analysing data from investigations, but to get the process of inquiry started, a few prompting questions can be posed. For example:

- For each part of the graph, what was happening in the investigation?
- What caused that peak?
- What are the highest and lowest values?
- How big was that change?
- How long did the change take?
- How quickly are values changing?
- What is the underlying trend?

- What sort of pattern is in the results?
- How does one variable seem to depend on another?

Again, the context determines the appropriateness of particular questions, but it would be useful if pupils have cultivated the habit of asking questions about their data, both during and after their investigation, and always seeking connections with their scientific knowledge of the context. Through sample exercises, pupils can be encouraged to build a repertoire of suitable questions for exploring data which are testable in software.

Having identified the desired learning outcomes for a task and framed questions to initiate exploration, teachers need to equip pupils with strategies for using tools for exploring data. Some suggestions are:

- view data from each sensor separately;
- look for trend;
- look at detail;
- compare two or more graphs;
- look for similarities and differences;
- plot one variable against another (a YX graph);
- calculate new data to match 'raw' data.

Such strategies are generic in that they can be applied to a wide range of different investigations and can be realised with a variety of different types of software. The software tools needed for manipulating and analysing the data tend to vary in availability and sophistication according to the chosen software, but the following set of features appearing in Logotron's Insight 2 now seems to be established as common usage:

<table>
<thead>
<tr>
<th>Tool</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zoom</td>
<td>To magnify a chosen portion of the graph</td>
</tr>
<tr>
<td>Join points: unjoin points</td>
<td>To emphasise a trend or discrete measurements</td>
</tr>
<tr>
<td>Cursors, with and without data-lock</td>
<td>For obtaining and comparing values on the graph</td>
</tr>
<tr>
<td>Bar display</td>
<td>To illustrate relative sizes and rates of change</td>
</tr>
<tr>
<td>Analysing aids: change, interval, ratio, gradient</td>
<td>To obtain further information from the graph</td>
</tr>
<tr>
<td>Calculating aids: smooth, define, trial fit</td>
<td>For calculating new data and describing relationships</td>
</tr>
</tbody>
</table>
Pupils need to invest a certain amount of time to gain familiarity and confidence in using these software tools, but experience shows that the time needed to bring pupils to an efficient threshold of skill can be quite modest (Rogers and Wild, 1994). Tutorial software now exists to help pupils acquire the necessary skills independently (Rogers, 1997).

To show how these principles are put into practice, four examples will be presented. They also illustrate a progression of sophistication. At the simplest level an investigation may consist of simple qualitative observations on the graph:
- picking out and commenting on notable features;
- describing a graph as a 'story'.

Example: Investigating the sound produced by a 'singing' kettle.

The progression from this is to a more quantitative approach involving obtaining numerical information:
- finding values for maxima and minima;
- measuring changes, gradients, etc.

Example: Investigating the rate of a chemical reaction.

At the highest level, groups of observations are linked and relationships are explored:
- identifying patterns, trends and connections;
- describing the relationship between variables.

Examples: Investigating an aquarium; Investigating current and voltage in a circuit.

Boiling water in a jug-type electric kettle made from plastic can be a noisy business: the spring-loaded switch gives a loud click; as the temperature of the water rises, a roaring or 'singing' sound develops into a crescendo; the sound begins to subside as the temperature nears the boiling point; at boiling the spring switch clicks off and, as the kettle gradually cools down, various creaks are heard. Placing a sound level sensor near the kettle can record the whole sequence of noises and the resulting graph (Figure 2) contains sufficient information to recount the story of the 'singing' kettle. As a simple detective game, pupils can be asked to examine the graph and speculate about the story behind the graph. The sudden peaks, the smooth stretches, the rising curves, the jagged sections all have a significance which contributes to the storyline.

This simple qualitative exercise in graph interpretation can be applied to a variety of phenomena recorded with the aid of data-loggers. The more variety in the data, the more interesting the story. Other examples include studying the weather, the temperature inside a fridge, the environment inside a motor car on a journey, the temperature of a greenhouse or conservatory over 24 hours. Such informal investigations can teach pupils to think about the symbolism of graphs.
Investigating a chemical reaction

In investigations to study the rate of change in a chemical reaction, changes can be observed in a variety of ways: changes of colour, temperature, changes from liquid to solid or gas. One of the commonest investigations uses the reaction between sodium thiosulphate and hydrochloric acid which deposits a sulphur precipitate, making the solution go cloudy. In the conventional method, pupils estimate the onset of cloudiness by noting the time for a cross on a piece of paper to disappear when viewed through the beaker containing the reactants. The IT method uses a light sensor and a data-logger to record the transmission of light through the reactants. As the graphs show (Figure 3), there is no clear cut-off point when the solution becomes cloudy; the process is gradual.

The graphs are a rich resource for investigation and can be conveniently studied in a variety of ways using software tools. However, to launch such investigation, it is useful to pose some suitable questions. Here are some suggestions for this investigation:

- How long does it take for the reaction to start after the solutions are mixed?
- Does the reaction proceed at a steady rate?
- How do you know when the reaction has finished?
- How long does it take the reaction to finish?
- If you dilute the solution, how does this affect the reaction time?

‘Action replay’

As a limbering up exercise, it is often useful to use the cursors informally to get a feel for the graph as a record of a sequence of events. Cursors (crossed lines which lock on to the data points) not only provide for reading values off the graph, but, used in conjunction with a bar display window, show visually the relative magnitude of values. Pupils can ‘replay’ the events of the investigation by slowly sweeping the cursor from left to right across the graph and observing the changing light level indicated by the bar display. The overall drop in the light level is shown clearly by the shrinking bar, but, more importantly, the variation in the rate of change during the reaction also shows up. This process of ‘action replay’ recovers some of the live experience of real-time logging but with the added advantage of being able to speed up or slow down the sequence of events by controlling the speed of the cursor movement.

Taking measurements

Using the cursors to take readings from the graph becomes a routine activity with software. In this case the maximum and minimum light values may be compared, but more interestingly the time for changes to occur can be measured in a variety of ways. Software provides a convenient tool for measuring time intervals from any chosen starting point on the ‘Time’ axis, but examination of the graph shape shows that it is not so easy to decide exactly when the reaction has finished. The little dip in the reading near the beginning shows when the acid was added but after that there is an S-shape curve with a long tail. A number of alternative approaches present themselves for taking suitable measurements:

- How long does it take for the reaction to start after adding the acid?
How long does it take for the light level to reduce to its middle value?  
How long does it take for the light level to reduce to its final value?

Using the cursors to measure time interval, each method can be easily tried and then evaluated. The important issue is not so much the value obtained, but its comparison with similar values when the investigation is repeated. In the example here, the second graph line shows the reaction for a more dilute solution. On each of the above measures, the time shows to be longer for the more dilute solution. Thus the comparison leads to the same conclusion, irrespective of the chosen method. This helps to foster the spirit of investigation in which pupils are often confronted with alternatives rather than right or wrong choices.

**Measuring rate of change**

Data-logging software is particularly good at helping pupils observe and measure rates of change. Considering the commonly available analysing tools, again there are several alternatives for measurement, each with their strengths and limitations. For this investigation, which is the more appropriate measure: the average rate of change during the reaction or the rate of change at a particular instant? If it is the latter, which instant should be chosen: near the beginning, or the middle, or the end of the curve, or the time when the rate is a maximum? If it is the former, what time limits should be chosen for calculating the average rate?

The average rate of change for a chosen portion of the graph can be measured using cursors set to give simultaneous readings of vertical ‘change’ and horizontal ‘time interval’ (Figure 4). A refinement of this facility calculates directly the ratio of the change to the time interval to yield the average rate of change. The most difficult part of the process is the decision on where to place the time interval limits on the curve; the middle, nearly linear part of the curve could be chosen, or a larger proportion of the overall vertical change.

The rate of change at a particular instant can be found from the gradient of the graph. The cursors can be defined to give a direct calculation of the gradient at a point. Moving the vertical cursor from left to right allows pupils to explore the changing gradient across the curve. The position for the maximum gradient can be quickly identified or, say, the gradient at the position when the change is half way through can be found.

Having chosen a strategy for measuring rate of change, the graphs for further trials with different concentrations can be investigated and compared. The same strategy must be applied to each graph so that it constitutes a ‘fair test’. It then becomes a fairly small step to draw a conclusion about the connection between the rate of change and the concentration of the solution. Carefully recorded readings show a linear relationship.

**Investigating an aquarium**

Recording light, temperature and dissolved oxygen measurements in an aquarium over a period of a few days is an ideal task for a data-logger. The Data Harvest Sense and Control EasySense allows this to be set up at the touch of a button. Using DCP’s LogITSL system, a progress report can be obtained each day, building up to a graph for the complete picture over several days.

This is a prime example of the graph as a starting point for scientific investigation. A general strategy might consist of seeking to answer these questions:

- What do we know about the context of the investigation?
- What can we learn from observations and analysis of the data?
- How can we connect these observations with the context?

In this case, pupils’ thinking about the context should include the knowledge about the cycle of daylight and the process of photosynthesis. Complete knowledge...
of photosynthesis is not important; the data collected in this investigation should stimulate questions about the process. Questions about the data can focus on:

- observing and describing the trends and variations in the data;
- taking measurements and relating them to the context;
- comparing data by considering similarities and differences.

There is a variety of ways of viewing and analysing the data (Figure 5). When the graph appears to contain a lot of information, it is a wise strategy to switch off the display of some of the data and concentrate on one variable at a time. Looking at the graph for light only, there appears to be an underlying trend showing up as peaks which are not identical but which seem to repeat in a regular fashion. These peaks show up very clearly when a smoothing function is used (Figure 6). Measuring the time interval between the peaks confirms the 24-hour cycle of daylight. There is much information to be explored here connecting with the context:

- Why are the peaks different heights?
- What causes the fluctuations in the ‘raw’ data graph?
- How does the graph shape indicate the season when the data were collected?

Looking at the graph for oxygen, a 24-hour cycle is again detected but the shape is completely different from the peaks observed for light. Comparing the similarities and differences between the light and oxygen graphs can prompt further thinking about the context.

**Investigating current and voltage**

In this investigation the data-logging method contrasts greatly with the equivalent conventional method, in terms of the quality and quantity of the data obtained, the opportunities for manipulating the data and the broadened range of possible learning objectives. The aim of the investigation is to study the relationship between the voltage across an electrical component and the current through it. The component to be tested is connected in a circuit in which the voltage is first increased up to a suitable maximum and then decreased. The voltage and current are measured continuously over a period of about 30 seconds and the results immediately displayed as a graph against time. Figure 7 shows results for a simple resistor. A considerable time ‘bonus’ is achieved in comparison with the conventional method which normally involves tabulating about 10 pairs of readings over several minutes. The following explorations suggest how this time bonus can be put to productive use.

**Looking for connections**

Essentially, a considerable amount of information can be obtained from the basic graph. From a conventional perspective it is unusual to present the current and voltages against time; it is more common to plot the current against voltage in the first instance. One of the advantages of the plot against time is the ‘action replay’ facility described earlier. As the cursor is slowly moved...
across the graph, the bar display shows two bars, one for voltage and the other for current, and they vary in height according to the sequence of readings. This visual display is very useful for focusing attention on the apparent synchronisation of the changes in each variable; as the voltage rises or falls, the current follows suit in a similar manner. Furthermore, for any particular voltage, the current can be predicted with certainty. There appears to be a direct correlation between the current and voltage values. This relationship can be explored in more detail using the cursors defined to calculate the ratio between two sets of values. In this way, it can be found that when the voltage is doubled, the current also doubles; when the voltage is trebled, the current also trebles, and so on. Whatever the ratio increase in the voltage, the current increases in the same ratio. This convincingly suggests that the current and voltage are related in direct proportion. An attractive feature of this method is that the relationship can be deduced directly from the properties of the readings revealed by the cursors.

Testing for linearity

The connection between current and voltage becomes clearer still when the axes are redefined to show current against voltage or voltage against current. Software makes it easy to set up either type of graph or swap between them. The resulting straight line reassures the tutored eye but its appearance should not be regarded as the conclusion of the investigation. The implications of the straight line for the relationship between voltage and current should be explored further using the cursor tools. The special properties of the linear relationship can be explored in a number of ways:

1. Read off the values of current for simple multiples of voltage, say at 1.0 V, 2.0 V, 3.0 V etc. – the current is also observed to increase in simple multiples.
2. Measure the increase in current for a given increase in voltage, starting at a variety of different places on the graph – equal increases in voltage produce equal increases in current, irrespective of the starting voltage for the measurement.
3. Measure increases expressed as a ratio – voltage and current increase in the same ratio, and the ratio of voltage to current is shown to be constant.
4. Find the gradient at different places on the graph – the gradient is the same everywhere.

Calculating and exploring new data

The investigation is usefully extended by plotting the electrical power dissipated in the resistor for the range of current flowing. The values for power are calculated as the product of corresponding values of voltage and current, but software makes light work of doing this for about 600 pairs of collected data. In this task, data-logging software has an advantage over spreadsheets in that the result is shown directly as a graph and omits the numerical tabulation of data. Studies have shown that few pupils can process information equally well with both tables and graphs (Dreyfus and Mazouz, 1992). This suggests an advantage in leaving out the table altogether and just showing the graph.

When the graph of power against current is displayed, again this should not be regarded as concluding the investigation. There is much to be done in exploring the relationship represented by the curve (Figure 8). Pupils should use the cursors to obtain readings, changes, ratios, gradients, and so on; then they should look for a rule, make predictions and check their predictions. The series of tests outlined above yields very different results compared with those from the current versus voltage graph:

- More current leads to more power, but this time the relationship is non-linear; the power quadruples when the current is doubled, suggesting a quadratic relationship.
- Equal increases in current produce unequal increases in power which tend to be larger for larger currents.
- For a certain ratio increase in current, the power increases in a larger ratio.
- The gradient of the graph increases with current.

Find the values of current for simple multiples of voltage, say at 1.0 V, 2.0 V, 3.0 V etc. – the current is also observed to increase in simple multiples.
New data-logging tools

Power and current for a resistor

In a sense, there is nothing new in these suggested investigations, for all these findings are also possible with manually drawn graphs. However, the time and skill needed to perform the calculations manually makes such exercises unjustifiable. In contrast, software provides ready-made tools for selecting, calculating and comparing values with speed and accuracy.

Describing relationships

The explorations described above focus on the numerical properties of the data. Perhaps the most precise method of describing data is to identify the algebraic function which relates two variables. This can be done by fitting or matching a known curve to the experimental data. Best fit facilities producing smooth curves or straight lines through the data are common in graphing software, but they should be used with discretion. The aim of the task should be to maximise the involvement of pupils and prompt thinking about the significance of the fit. This might be done by first challenging pupils to predict the type of line that is likely to fit and then to check their prediction. Further, they could have some control over the selection of the function to be fitted and its parameters. The significance of curves and straight lines comes from knowledge of their properties which can be gained from the numerical explorations outlined previously.

Conclusion

The examples presented here have illustrated how graphs from data-logging investigations can be used for encouraging thinking about data. Data can be explored in a variety of ways, providing many new experiences and insights into the properties of the data. Many alternatives are presented and the design of a task requires a clear vision of the learning objectives so that contextual questions can be set. Ideally, tasks encourage pupils to develop the habit of asking questions about the data and making links with their science knowledge. Pupils' familiarity with the software tools speeds up the process of obtaining answers but they also need to be given strategies for using the tools and evaluating and selecting the alternatives.

References


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‘Data-logging - Effects on practical science’ (with P. Wild)


This paper reports on the Classroom Observation Project which aimed to identify and measure beneficial changes occurring in practical lessons when data-logging methods were introduced.
Data-logging: effects on practical science

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Abstract This paper describes an investigation into the processes and effects of using electronic data-logging in practical science. A pilot study of classical laboratory work in schools was compared with similar tasks performed with data-logging systems. A more detailed exploration of pupils' performance was then conducted through an extensive series of observations in a range of secondary schools. The results reinforce previous indications of the potential benefits of data-logging, but such benefits must be viewed in the curriculum context of the type of measurement activity and the pedagogical context of teaching and learning objectives. The paper concludes with a discussion of the latter issues.

Keywords: Data-logging; Information technology; Secondary schools; Science; Laboratory

Introduction

Since the early 1980s the use of computers in schools in the UK has developed from beginnings as an extension of the teaching of mathematics to a broad and sophisticated range of activities embracing the whole curriculum. In science, an important development has been the application of computers to laboratory work, involving measurements using sensors, interfaces and data-loggers. (Outside the UK this type of activity is often referred to as MBL — microcomputer-based laboratory.) Despite the fact that the software and hardware tools for this type of activity are now refined and very easy to use, school science departments have been rather slow to adopt data-logging technology (OFSTED, 1995). The reasons for this reticence are often cited as a mixture of limited funds, limited time and limited training opportunities for science teachers (NCET, 1993; Barton, 1994). It is also possible that limited awareness of the learning benefits has caused a failure to gain the professional commitment of teachers.

Recently, the adoption of this technology in schools has been encouraged by Government legislation and funding initiatives; with the introduction of the National Curriculum, specific targets for the use of IT were identified; a

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DFE funded programme evaluating portable computers and a further programme of GEST* funding, have sponsored the purchase of equipment and the inauguration of many projects in schools exploring IT in science. These initiatives appear to have been driven by progressive professional opinion of the benefits of IT rather than by a core of research evidence. Indeed some of the meagre research evidence available appears to give only weak support to the learning benefits of IT (Hammond, 1994).

An improved understanding is needed both to justify funding and investment initiatives and to persuade professionals that the innovation is worthwhile on educational grounds. Accordingly, the aim of this study was to examine the use of data-logging methods in school science laboratories to look for evidence of the educational benefits claimed for the technology.

The theoretical base for the study

It is easier to describe data-logging activities (Frost, 1995) than to define their benefits to pupils' learning and understanding of science. Reports on the claimed benefits fall into two main categories. First, many reports really only refer to the technical features of hardware and software and their method of application rather than the measured outcomes and gains in learning. They are also mainly articulated through professional opinion and anecdotal evidence rather than through rigorous investigation. Two examples of such lists of advantages of data-logging are:

- extend pupils' powers of observations;
- improve the quality of measurement;
- record data in informative ways;
- facilitate interpretation (comparing data etc.);
- provide calculating and analysing aids for investigating data;
- communicate results to bring out their significance;
- motivate pupils through prompt feedback. (Rogers, 1987)

- enhance learning by extending the range of student investigations;
- usable by the novice;
- can encourage critical thinking skills by reducing the drudgery of data collection;
- can encourage learning from peers;
- may be an effective means of teaching graphing;
- may make the abstract 'concrete' through immediate feedback. (Thornton, 1987)

Secondly, there are reports of research which has seriously attempted to evaluate the educational potential of data-logging and to identify the effect of the technology on skills associated with learning science. Amongst such skills, graphing skills have been strongly linked with the process of investigating scientific relationships (McKenzie & Padilla, 1986). Studies have shown that pupils' interpretation of graphs is significantly improved

* The UK Department for Education (DFE) supported the Grant for Educational Support and Training (GEST) initiative.
when using MBL (Mokros & Tinker, 1987). It has been argued that special features of graphing software provide useful aids to help pupils overcome a variety of difficulties normally associated with manual methods of manipulating graphs (Rogers, 1992). It has been recognised that the use of IT encourages high order skills (HMI, 1989) and facilitates the development of scientific reasoning skills used in problem solving (Friedler, et al., 1990). Skills of graphical interpretation develop very quickly in real-time reporting where the graphic representation is promptly linked to events, and they also show strong links with reflection and interpretation (Brasell, 1985).

Unfortunately, much of the relevant research published to date pre-dates the rapid developments of microcomputer technology during the early 1990s. In particular, significant advances in software design have made available graphical user interfaces which have transformed the usability of computers in education. Also, in the UK, there have been great advances in the design of sensors and interfaces for data-logging which has made the technology much more accessible and available for use in regular classrooms. These changes call for a review of the existing research evidence and fresh research into classroom application.

The pilot study

The aim of the first phase of research was to test the notions of the value of data-logging by investigating the reality of classrooms where these methods were in use. An attempt was made to identify and measure the potential contributions of data-logging to the quality of learning from the practical work. In addition, the research sought to uncover attitudes and opinions of both pupils and teachers about the influence of IT.

The research was conducted in three secondary schools over a period of nine months and employed a range of techniques: observations of lessons, pre-test and post-tests for pupils, interviews with pupils and discussion meetings with teachers. The age of pupils ranged from 12 to 15 and groups were chosen to represent a spread of ability. Lessons and topics were chosen in such a way that the work fitted into the curriculum with minimum disruption to the normal routine. Overall, the observations spanned a diversity of teaching styles and lesson organisation. In each situation, groups of pupils were observed on parallel tasks; some groups used IT whilst others used conventional non-IT measuring methods. The chief objective of the observations was to compare the performance of the two types of group.

A full description of the pilot study has already been reported (Rogers & Wild, 1994). This paper restates the principal pilot findings and shows how these were used to design the main study.

Pupils' tests

In each school, teachers devised tests to assess their objectives of the lessons containing the practical activities. The topics of the lessons ranged from heating and cooling, motion measurements and electrical measurements.
Most of the lessons contained an element of graphical presentation and analysis. In most cases similar tests were given to pupils before and after the practical activity. In some cases standard end-of-module tests were used as well. In only one of the three schools did the results of the pre-tests and post-tests show any significant bias in favour of the IT groups. An interesting feature of this case was that the main demand in the tests focussed very strongly on the analysis of graphs. This is significant because it is in graph work that computer software offers many facilities for manipulating and obtaining information. Thus the enriched experience gained from the use of the computer appeared to have a beneficial effect on pupils' test performances. In contrast, for the tests used in the other two schools, the use of the computer appeared to confer no advantage. Close scrutiny of the design of these tests showed that they tended to reward knowledge and skills which were not particularly amplified by the use of the computer.

Lesson observations
During a number of selected lessons, groups of pupils were observed systematically using a schedule to analyse the time spent on various types of task. Comparing the time profiles of IT and non-IT groups there was a trend whereby IT groups spent more time in discussing their data, and they tended to move on to discussion and extension questions sooner in lessons. This changed emphasis towards discussion and thinking activity supports the generally agreed view amongst the teachers that IT had proved to be a valuable tool for promoting an investigative approach.

Teaching style
For the researchers, one of the most significant outcomes of the pilot study was the indication that positive teaching strategies were needed for exploiting the opportunities afforded with IT. For example, it may be claimed that the increase in time pupils spent on discussing results was not assured through the use of IT alone; the teacher had a crucial role in developing pupils' skill to discuss effectively. The software merely provided the tool for prompting discussion and inquiry and its success had to be developed through a classroom culture which encouraged pupils to ask questions and explore their ideas. As another example, the teacher can develop a new approach to graphwork responding to the fact that the computer generates the graph with such ease and flexibility.

Indicators from the pilot study
The most positive effects of IT indicated by the pilot study relate to the character of pupils' activity rather than measures of their achievement. It was difficult to draw any firm conclusions about the quality of learning within the time scale of the lesson activities in the study. However the apparent shift in emphasis from the mechanical aspects of measurement towards discussion and thinking activity, and the need to review lesson objectives when using IT deserved further detailed investigation.
The main study — observations of practical lessons

The main phase of research aimed to test the hypothesis that pupils using IT spend more time discussing and evaluating their results compared with pupils using conventional measuring methods. Evidence was gathered through observations of groups of pupils in practical lessons in eight schools over a period of 18 months. A systematic schedule for making observations was devised and used by five researchers who visited a variety of lessons involving the use of IT methods and conventional methods of measurement.

Design of the observation schedule

The purpose of the schedule was to systemise observations to find out the frequency and approximate duration of different types of pupil activity in the lessons which might, but not necessarily, include the use of IT. It was designed to be applied to the mainstream of practical lessons where pupils are organised into working groups of about three or four.

A number of categories were defined for the purpose of classifying the type of activities expected in typical practical lessons. The categories were chosen to correlate with ATI strands defined in the National Curriculum, but since these did not cover all needs, others were added. Overall, the number was limited so that the schedule was manageable in the classroom. Categories were grouped into five areas (Table 1) which describe the main phases in typical activity: Preparing, Doing, Reflecting, Reporting, Other.

<table>
<thead>
<tr>
<th>Category</th>
<th>Type of activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparing</td>
<td>1 Asking questions</td>
</tr>
<tr>
<td></td>
<td>Predicting</td>
</tr>
<tr>
<td></td>
<td>Hypothesising</td>
</tr>
<tr>
<td></td>
<td>Planning</td>
</tr>
<tr>
<td>Doing</td>
<td>2 Handling apparatus (collecting, assembling, &amp; adjusting)</td>
</tr>
<tr>
<td></td>
<td>3 Measuring (getting data)</td>
</tr>
<tr>
<td></td>
<td>4 a) Observing</td>
</tr>
<tr>
<td></td>
<td>b) Manipulating variables</td>
</tr>
<tr>
<td>Reflecting</td>
<td>5 Interpreting results: analysis</td>
</tr>
<tr>
<td>(discussion)</td>
<td>(getting more information)</td>
</tr>
<tr>
<td></td>
<td>Evaluating scientific evidence: Making sense of the data</td>
</tr>
<tr>
<td>Reporting</td>
<td>6 Describing: a) oral; b) written</td>
</tr>
<tr>
<td></td>
<td>7 Drawing graphs</td>
</tr>
<tr>
<td>Other</td>
<td>8 Off-task</td>
</tr>
<tr>
<td>Hybrid activity</td>
<td>E EXPLORING (Mixture of 'Doing' and 'Reflecting' activities)</td>
</tr>
<tr>
<td></td>
<td>D DISCOVERY (The 'penny drops'; &quot;Look at that!&quot;)</td>
</tr>
</tbody>
</table>
In the traditional style of directed practical work the sequence is often linear but for an investigation style of working the sequence is more likely to be cyclical in which the reflection phase leads to further preparing and doing. These phases were further subdivided to create the main categories which were recorded on a grid record for each lesson.

The interpretation of the categories were discussed at length by the five researchers to gain a consensus and a common set of guidelines was agreed. Category 3 (Measuring) was intended to focus on the skill of getting data. With conventional measuring instruments this involves obtaining numerical readings and recording them. However, with the computer, pupils are more likely to be observing in some manner (4a), or reflecting (5) or other (8). Category 4a (Observing) described qualitative rather than quantitative outcomes. Category 4b (Manipulating variables) involved pupils making decision about and altering parameters in an experiment.

For category 5 (Reflecting), it was necessary to give a clearer focus to the term 'discussion' to identify in particular the reflective type of discussion associated with scientific thinking (interpreting, evaluating, predicting, hypothesising, asking questions, etc.). This was to be distinguished from discussion associated with operational matters such as the logistics of handling apparatus (category 2) and obtaining results (category 3).

The main purpose of the research was to focus on pupils' activity but it was recognised that, inevitably, the teacher's activity permeates the lesson as they naturally take a lead through asking questions, explaining, giving instructions, prompting, providing help, giving hints etc. For the purpose of the observation record, the time when the teacher assumed the leadership role was identified and these instances were excluded from the main analysis. Further information about the context of the lesson was also recorded: ability of groups, gender, topic, teacher, previous IT experience.

Results from the classroom observations

Collection and analysis of the data

Eight schools agreed to participate in the study on the basis that researchers would be invited to visit and observe practical lessons on occasions when IT happened to be in use. Thus classes were chosen for observation on the basis of convenience rather than through a statistical sampling process. None of the observed lessons were specially staged for the study; all occurred as part of the normal curriculum and were taught by their normal teacher. Each school had prepared its own materials and retained its usual autonomy over the planning and conduct of individual lessons. The method of using IT was totally at the discretion of each class teacher. The researchers took no part in determining the approach adopted in lessons; their role was simply to observe particular groups of pupils during lessons. Pupils were in the age range from 11 to 16 years. In general the groups were chosen to represent a cross section of pupils in each class. Where it was possible to observe a sequence of lessons, the same groups of pupils were observed. All pupils had previous experience of using computers and most had used data-loggers.
before, but some were using data-loggers for the first time. Observations were not confined to groups using IT; about one third of the observations were of conventional measurement methods.

Total number of pupil groups observed: 70
Number of groups using IT: 49
Number of groups not using IT: 21
Number of lessons observed: 26
Cumulative time on observations: 48 hours

The accumulated data was analysed to obtain a profile of the time pupils spent on each category of activity expressed as a percentage of the total observed time. The profile was further analysed to compare the patterns of activity in the following conditions:

- Use of IT compared with conventional measurement
- Effect of IT on experiments on the topic of motion
- Effect of IT on experiments on heating and cooling
- Effect of IT when an investigative approach is emphasized

**Effect of using IT**

In general, when IT is used, the pattern of activity tends to show a shift in emphasis away from time spent on preparing, measuring and reporting towards more spent on observation and discussion (Fig. 1). This supports

![Fig. 1 Comparing practical activity with and without the use of IT.](image-url)
well the findings of the pilot study and earlier expressions of professional opinion (HMI, 1989; Rogers, 1987). However, it is perhaps surprising that more time is also spent on handling apparatus. This finding seems to be contrary to the impression expressed by some teachers that the data-logging process manages too much for pupils and reduces the amount of 'hands-on' activity. Some of this additional activity must be associated with setting up the computer and logging equipment as well as the laboratory apparatus, but this may be offset in part by the reduced time spent on gathering data.

The profile also shows a greater time spent off-task for IT groups. This might suggest that pupils failed to profit from the time saved from not having to draw graphs manually. Some of the observations indicated that occasional equipment failure or logistical problems (such as a queue of pupils waiting for the single printer in the laboratory) were responsible, but these did not account for all of the time. It seems appropriate to evaluate the targets set for the pupils and consider how they might use the spare time to better exploit the opportunities for analysis offered by the software. This point will be revisited in the final discussion.

Although the main observation focus was on the distribution of time for the categories of activity, some other descriptive comments on pupils' achievements were noteworthy:

There was a clear differentiation in activity depending on IT or non-IT experiments. Pupils using IT/lap-tops moved quickly on to observation, variable manipulation and discussion, despite initial lack of familiarity with apparatus and software.

The facility of automatic data-logging and graphical representation, allowed for a more focused approach to variable changes and discussion of results. The print-outs available gave the pupils easily accessible material and insight ready for a good write-up for homework.

The non-IT experiments involved activities concentrated in the hypothesis, handling of equipment and data collection sections. Outcomes in terms of data collection were varied to say the least. Some groups managed (by skilful division of labour) to get tabulated data ready for representation and interpretation, but others barely reached this vital stage.

**Effect of type of experiment**

The pattern of activity (Fig. 2) is shown to depend upon the type of experiment. Superficially, the context of the topic of the experiment reveals obvious differences in the type of apparatus used, the skills needed for its manipulation and the nature of the tasks being set. Within the range of observations two types of activity occurred most frequently; experiments involving heating or cooling and experiments involving timing measurements. The distinctive differences between them are:
• Heating and cooling experiments involve the use of temperature sensors, real-time display of graphs, continuous recording of results.
• Motion experiments involve the use of light gates, discrete measurements of time, and place less emphasis on graphical display, certainly not in real-time.

Of the 49 groups using IT, 15 involved experiments on heating or cooling and 14 involved experiments on motion. Observations showed that for temperature measurements, more time was spent on getting measurements and discussing results. For timing measurements, a greater proportion of time was spent on handling the apparatus and making observations.

These results suggest that it is too simplistic to look for the effects of IT in a bland general way without regard to the context of its use. Context seems to be crucial. For traditional laboratory activity this is perhaps more obvious where the typical school repertoire of experiments contains a wide variation in the intensity of involvement of pupils; manipulating apparatus, making observations, taking readings, controlling variables etc. The observations suggest that IT-based experiments are likely to exhibit a similar diversity of physical and procedural demands.
Data-logging: effects on practical science

Effect of teaching style
In the opinion of the researchers the teaching style of lessons observed in two schools was identified as strongly emphasizing an 'investigative' approach to practical work, compared with other schools. In one case, there was a clear tradition of pupils designing their own experiments to find answers to questions identified through class discussion and in reporting on their decisions as work progressed. In the other school there was a prevalent culture of discussion with and by pupils. The observations showed that, in these schools, pupils spent longer on (measuring and) discussion activities. This suggests that, although overall the use of IT was generally associated with more discussion, the effect was more marked when an investigative teaching approach is also used.

Table 2. Observation of IT use

<table>
<thead>
<tr>
<th>Groups using IT</th>
<th>Frequency of 'Reflecting' (%)</th>
<th>Range (%)</th>
<th>Number of groups observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>School A</td>
<td>21%</td>
<td>0 - 42</td>
<td>15</td>
</tr>
<tr>
<td>School B</td>
<td>26%</td>
<td>9 - 41</td>
<td>8</td>
</tr>
<tr>
<td>Other schools</td>
<td>10%</td>
<td>0 - 36</td>
<td>26</td>
</tr>
<tr>
<td>All schools</td>
<td>17%</td>
<td>0 - 42</td>
<td>49</td>
</tr>
</tbody>
</table>

Learning to use IT
Many classes observed were still in the innovation stage with IT; i.e. a lot of effort was being consumed in learning to use the new tool; getting to know the computer and software and evolving a strategy to cope with the logistics. The observations encompassed a great deal of initial learning and the improvements which accompanied the process. At one school this improvement was recorded over four lessons with pupils talking to each other and spreading useful tips. This highlights another aspect of teaching style, the concept of the pupil as a teacher as well as learner. This is possible when the teacher is prepared to step aside a little and encourage pupils to help each other.

Summary and Discussion
The pilot study revealed how difficult it was to conduct research on a short time scale and draw conclusions about the effect of IT on the quality of learning. With only limited resources available to the project, this experience directed the main study to focus on a more quantitative approach to observation. As previously described, these results demonstrated quantitative changes in the time spent by pupils on different categories of activity when IT was used: the traditional emphasis on the mechanical aspects of measuring, recording and reporting in conventional practical work was diminished, with a commensurate enhancement of time spent on observation and discussion. This indicated potential for IT to facilitate a greater emphasis on 'higher order' skills, but the qualitative findings from
the study indicated that the noted effects were much more context dependent than had been originally expected. The principal contextual factors were:

- the quality of exploitation of the computer tools;
- the physical nature of the topic under investigation;
- learning objectives;
- learning style (pupil autonomy; investigation).

In order to discuss the effect of these factors, it is helpful first to reconsider in greater detail the claimed benefits of data-logging. Many of them are essentially no more than descriptions of the properties of data-logging software and hardware systems which confer 'added value' to the measurement process. As such, it is reasonable that they are adequately supported by professional opinion and do not require vindication through rigorous tests. For example, the reduction in manual effort needed to draw graphs is self-evident from simple observation of the software itself. However, in assessing the benefits of such properties, these are only provisional, and depend upon the context of the application. A refined list of properties and their associated potential benefits is proposed.

Table 3. Properties of IT and their potential benefits

<table>
<thead>
<tr>
<th>Properties of IT which add value to practical work</th>
<th>Potential benefits (dependent on context of application)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New contexts for gathering data</td>
<td>Pupils are less dependent on secondary information. They can gather their own data in a wider range of situations.</td>
</tr>
<tr>
<td>(e.g. transient phenomena, logging over long periods, remote logging)</td>
<td></td>
</tr>
<tr>
<td>Reduced manual effort to obtain graphs</td>
<td>Lower level of skill needed for graph plotting. Time bonus.</td>
</tr>
<tr>
<td>Real-time reporting</td>
<td>Interactive: display-question-test</td>
</tr>
<tr>
<td></td>
<td>Time bonus</td>
</tr>
<tr>
<td></td>
<td>Encourages gathering more data</td>
</tr>
<tr>
<td></td>
<td>Encourages thinking about data</td>
</tr>
<tr>
<td>Accuracy of readings (Less dependence on reading instrument scales)</td>
<td>Reduced errors - better quality information</td>
</tr>
<tr>
<td>Accuracy of reporting (Automatic storage of data)</td>
<td></td>
</tr>
<tr>
<td>Tools for calculation and analysis</td>
<td>More information available</td>
</tr>
<tr>
<td></td>
<td>Accurate derived information</td>
</tr>
<tr>
<td></td>
<td>Time bonus</td>
</tr>
<tr>
<td>New methods of exploring data</td>
<td>New insights into data - identifying patterns and trends</td>
</tr>
</tbody>
</table>
property, one or more benefits which have been observed in the classroom studies are suggested, but these may not be assured simply by the use or occurrence of the property alone; the contextual factors noted previously have been shown to have a significant influence on how effectively properties can deliver benefits.

**Quality of exploitation of the computer tools**

A certain threshold of IT capability is necessary for pupils to use data-logging software successfully for basic operations such as collecting data from sensors, adjusting graph displays and saving data. The study has illustrated many examples of pupils rapidly gaining confidence and familiarity with this level of use. The amount of teaching time needed for investing in these skills is quite modest, particularly in view of the now common use of graphical user interfaces (Windows, RISCOS etc.) which enable many of these skills to transfer readily from experience gained elsewhere in the curriculum. The speed with which pupils pick up these skills compares extremely favourably with that normally required for learning to plot conventional graphs manually! However, it is suggested that the potential of the software is generally under-used. Full exploitation not only requires knowledge of facilities available in software but also vision of how the tool or method might be used for scientific enquiry. The initial investment in skill needs to include techniques which enable pupils to test hypotheses, discover patterns in data or to obtain further useful information about data. Thus pupils need to understand more about the application of the software, and in particular the potential of the analysing aids.

**Physical nature of the topic under investigation**

The earlier list proposed a summary of properties of IT which add value to practical work. In any particular experiment it is unlikely that the full range of properties are relevant. The physical nature and design of an experiment naturally limit the relevant properties to a subset of this list. From the observations it is possible to identify two groups of experiments which illustrated a clear distinction of procedural and analytical demands. Experiments on motion using timing measurements required pupils to be busy controlling the apparatus and the measuring process. Here there was plenty to do and the main value contributed by IT lay in the accuracy of results and their prompt calculation into values for velocity and acceleration. In contrast, the heating and cooling experiments with temperature measurements required a much lower intensity of effort. Here, the emphasis was on real-time reporting, which was potentially very exciting because it offered the possibility of testing ideas immediately and working interactively. However, there was always the risk that the time bonus was under used, the most obvious danger being that pupils might merely watch uncritically as the computer displayed the results on the screen. Comparing these two types of experiment, they employed different properties of IT and any evaluation of the role of IT needs to recognise the different benefits which flow from each.
It is not difficult to extrapolate this idea to the distinctively different modes of logging and construe that each has particular benefits. For example, 'real-time' logging (immediate reporting of results) contrasts with 'remote' logging where data is accumulated away from the computer and viewed retrospectively. Similarly, 'rapid collection' of data (short transients etc.) contrasts with 'longer term collection' lasting hours or days. The latter types of IT usage, such as collecting environmental data continuously for a week, have no traditional counterpart, making comparison and evaluation difficult (Hammond, 1994).

A further aspect of the physical context of the experiment concerns the properties of the sensors used. For example when a temperature probe is placed in a liquid it normally takes a certain time for it to adjust to the ambient temperature. This of course is also true of conventional mercury thermometers but the difference is that data-logging collects the data in such detail that the effect is much more obvious. Similarly, the effect of stirring a liquid with a temperature probe can be dramatic and there were instances where neighbouring groups of pupils obtained apparently different graphs from similar experiments. At first sight the data appeared to be of doubtful quality. In fact the reverse was true; much more information was captured, offering more opportunities for thinking about the science involved. This suggests that it is appropriate to have a broader view of what is useful information and a strategy for taking advantage from it.

Learning objectives
The table of potential benefits (Table 3) contains several instances of a 'time bonus' i.e. where the use of IT confers a saving of time compared with conventional methods. It is a necessary challenge for the teacher to rethink lesson objectives and manage pupils' activity to take advantage of this which can only be considered a benefit if the time gained is put to use in a profitable and purposeful way. Unfortunately the time profiles generally indicated an increase in the amount of off-task time when using IT. This is not to suggest that all off-task activity is necessarily bad; pupils' concentration can be improved after a rest or a change (Merry, 1995). However, from the observations, which partly drew upon listening to snatches of pupils' conversation, it seemed that much off-task talk was unproductive.

In general, most of the proposed properties of IT (data-logging) make it appropriate to set more ambitious objectives for pupils' activity. For example, the reduced effort in obtaining graphs gives pupils of lower ability better access to this visual medium for analysing data. At all levels the graph can be seriously considered as a starting point for activity rather than the culmination of a lesson's work; the data can be re-presented in such a variety of ways, the graph becomes a tool for exploring and thinking about the data (Rogers, 1995). Software tools for calculation and analysis reduce formerly tedious and repetitive tasks and transform them into creative opportunities. For example, in an experiment to find out how the mass of a trolley affects its acceleration on a slope, the prompt calculation of
acceleration from time measurements enables pupils to repeat, many times over, the cycle of changing the mass, predicting the effect on the acceleration, and then measuring acceleration. Thus many more cycles of predict-and-test are possible in a lesson.

In setting new objectives, teachers need a good knowledge and understanding about what IT is particularly good at achieving, and a clear rationale for the purpose of activities so that sound judgements can be made about the appropriate rather than indiscriminate application of IT. Finally, assessment objectives also need to be adapted to reflect revised learning objectives.

Learning style
An underlying theme in the list of properties of IT is the enrichment of pupils' practical work. New contexts for gathering data, new tools for calculation and analysis, new methods of examining data, together with prompt graph display, real-time reporting and improved accuracy, all offer potential to encourage pupils to explore and ask questions about data. Exploration is a key aspect of exploiting the software tools. To encourage exploration it is important to develop pupils' self-confidence to find out for themselves. This is not simply an issue of acquiring knowledge and skill with the software, it is fundamentally a matter of teaching and learning style. If pupils have the habit of waiting to be told what to do next, this is very limiting. It is much more desirable for them to become used to taking initiative. In particular they need to cope with the time bonus. It is suggested that a strategy which prompts and enables them to ask lots of questions about the data and its interpretation is most likely to succeed. For example, pupils might be encouraged to compare sets of data; they can look at each other's graphs, discuss the differences and similarities or compare their graph with that of sample data. Hopefully, as discussed earlier, they might learn to take a broader view of what constitutes relevant and useful information. As Goldstein has remarked: "Teachers must be careful not to allow pupils to develop the habit of ignoring signals." Discussion and asking questions are facilitated by small group work which is the traditional strategy for organising practical work in the school laboratory. The time profiles have shown, that discussion occurs even more frequently when the computer is introduced to group work. In addition, discussion is often better focussed when it is prompted by real-time reporting because of the immediate context of the results being revealed.

Overall, an investigative approach tends to embody what pupils need to take advantage of the benefits of IT. This does not imply stylised whole investigations as the only suitable methodology; it rather indicates an attitude towards scientific inquiry which is not exclusive to practical work, but which can permeate a variety of learning activity in science. In the study, this is supported by the time profiles for the two schools deemed to have emphasised this approach. Decisions taken by teachers on matters of teaching and learning style are also bound up with decisions on learning objectives. A deterministic approach to experiments, in which the goals consist of obtaining single outcomes such as a physical constant or the
verification of a known relationship, is not one which encourages exploration. Instead, objectives should be sought which encourage pupils to search for meaning in scientific data and make links with relevant scientific knowledge.

Despite the apparent emphasis here on pupil autonomy, there is also an underlying theme of the crucial role of the teacher in determining the style of learning and in providing the appropriate conditions. Indeed, throughout the study of the implications of using IT tools, the teacher emerges as a key figure. This is in common with the findings other related studies. For example, the management of small group work requires sensitive handling by the teacher if pupils' discussions are to be both creative and yet a disciplined activity (Cowie & Rudduck, 1992). One of the most recent studies of how children learn science has underlined the importance of teacher's interventions for introducing the cultural tools of science and for providing the support and guidance for pupils to make sense of these themselves (Driver et al., 1994).

Conclusions

This study has shown that the use of IT changes the time profile of activity in practical lessons. The greater proportion of time involved in observation and discussion suggests more thought and reflection. Clearly the quality and nature of these need further detailed investigation, but if thought and reflection can be successfully promoted through the use of IT, the prize of better scientific understanding is possibly within reach. It has been argued that the properties of data-logging provide ample encouragement for thinking, but have concluded that the magnitude and quality of this benefit depend upon their application and the conditions surrounding their use. Another recent major project has successfully used computer simulations in science to promote more sophisticated reasoning and conceptual change (Hennessy et al., 1995). Here the simulations were used as a partial substitute for practical work. One might speculate that an even greater improvement might be possible with a blend of data-logging activity for the practical component of the lessons. Some of the application factors which enable data-logging to deliver benefits have been suggested, and attention has been drawn to the beneficial effect of a learning style which embraces an investigative approach.

At this stage it is proposed that teachers adopt the following strategies which seem to offer the most promise from data-logging:

- gain a full awareness of the potential of software tools;
- review and redefine objectives of practical activity;
- give pupils freedom to explore; encourage a questioning approach.

The next phase of research needs to examine more carefully these application factors rather than the technical properties of data-logging itself.
Data-logging: effects on practical science

References


This paper reports on the evaluation of the OILS software *Understanding Insight*, designed to assist pupils in developing their skills in experiments with data-logging hardware and software.
Integrated Learning Systems – an ‘open’ approach

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and Leonard Newton, Department of Education, Loughborough University, Loughborough, UK

Studies of Integrated Learning Systems have endorsed their potential for enhancing pupils’ learning, but they have also highlighted the importance of the context and method of use in influencing the nature and quality of the learning outcomes. This paper describes an evaluation of a new version of this type of software which is explicitly designed to make links with several external factors, in particular with another software application for supporting investigative work in practical science. The evaluation adopts a situated approach which explores the contributions to the learning process made by the teacher, the student as well as the software itself. The results amplify the value of small group working, the role of the teacher and the aspects of software design which help to secure the benefits of the system.

Introduction

The recent decade has witnessed an intense public debate of educational standards in schools in the UK and, with the concurrent burgeoning of Information and Communication Technology (ICT), there has been wide interest in exploring the potential of this technology for improving the effectiveness of teaching and learning. In the field of intelligent tutorial systems, bold claims have been made for Integrated Learning Systems (ILS) for supporting the whole curriculum, and extensive research has been conducted in evaluating such systems (Underwood and Brown 1997). The early phase of research showed promising results under certain conditions and this prompted a government initiative (NCET 1994) to develop a more flexible approach which might better support the diverse needs of schools. The flexibility envisaged incorporating the use of a range of third party software already present in schools. This paper focuses on one of the development projects sponsored by the ‘Open Integrated Learning System Materials Development Scheme’ (OILS).

The ILS concept

An ILS is a computer-based system that manages the delivery of curriculum material to students so that they are presented with individual programmes of study. As students work, the system provides feedback for both students and tutor; students receive immediate evaluations on their responses and tutors obtain detailed records of the students’ performance. There is no definitive specification of an ILS as a class of system; individual systems vary in the range and sophistica-
tion of their features according to the learning objectives supported; however, the common elements of a system are as follows:

- **Curriculum content** – a range of tutorial, practice and assessment modules;
- **Student record system** – recording information on each student’s achievement; and
- **Management system** – for supervising the tasks and monitoring student data.

In evaluating an ILS it is clearly important to consider the quality of the pedagogy and integrity of the curriculum content, however the crucial aspect in which an ILS must be judged is the sophistication of its management system. All systems enable detailed monitoring of students’ progress. Some systems contain diagnostic elements which can plot pathways through the curriculum modules matching the pace and level of the students’ individual needs. Fulfilling these needs is one of the chief merits of an individualized learning programme in any medium and an important aspect must be the quality of the matching process; for students to progress at a suitable individual pace, they need to be stretched, but not overwhelmed, by the task. This requires a learning environment with a suitable balance between the demand, support and feedback in tasks.

**The strengths and weaknesses of ILS**

Integrated learning systems have received thorough evaluation in the UK and the results support the claim that they enable pupils to learn, but, more importantly, they prompt discussion of what and how they learn (Underwood and Brown 1997, Wood 1998). The greatest learning gains are identified in basic mathematical and English skills and, as with many evaluations of innovations in education, the magnitude of such gains appears to be linked with the way in which the technology is used in the classroom. Factors which have been shown to have a positive influence include the degree of integration of ILS in the curriculum, the extent to which the ILS content is linked with other curricular activity, the accurate placement of students in the system, teachers’ interpretation of reports and the quality of pedagogical support (Brown 1997). With most of these factors coming under the control of the teacher, and being subject to their attitude and skill, it comes as no surprise that there is a long history of research which underlines the importance of the role of the teacher in determining the quality of learning gains with ILS (Schnitz and Azbell 1990, Becker 1992, Lawson et al. 1997).

In the affective domain, there are several benefits which are so frequently reported that they can be regarded to endure a wide variety of external factors. In use, an ILS tends to be associated with good behaviour patterns, good attention and a calm working atmosphere (Underwood et al. 1994). As a method of working, an ILS is often motivating and very popular with students (Hativa 1989). Many students find the individualized mode of working encouraging, where they get instant feedback and their results are not made public (Cavendish et al. 1977). It has also been shown that students even make better learning gains when they work in co-operative pairs rather than as individuals (Mevarech 1994).

The provision of feedback is a valuable strength of ILS which makes an important contribution to students’ motivation and encouragement. Immediate feedback improves confidence and is especially effective when it is adaptive, that is, being able to accept alternative answers, diagnose causes of error and offer
corrective advice (Azevedo and Bernard 1995). Unfortunately, the UK evaluation reported a general lack of adaptive features which must be regarded as a weakness in currently available ILS systems (Brown 1997).

A further notable weakness is that ILS systems appear to make little impact in improving skills in reasoning and interpreting problems. In the current UK context this is a significant weakness, in view of the current emphasis on assessment techniques which require reporting across a broader profile of skills than basic skills and acquired knowledge. Wood argues that the concept of knowledge in present integrated learning systems is possibly too limited, that it does not embrace ‘knowledge residing in a grasp of relationships (for example, similarities and differences) across different ways of interpreting, representing and working with information’. ‘ILS tends to concentrate too much on teaching single ways of representing and solving problems, so the ability to teach “deeper” conceptual meaning is too weak’ (Wood 1998). This is clearly an aspect in which further developments are needed. A possible remediation with current systems is in the hands of teachers who can familiarize students with alternative representatives, help them make the connections and explain relationships.

The OILS concept

Recognition of the gap between what an ILS has to offer and the demands of the curriculum and its assessment has posed a challenge to software designers. Some interesting questions which might be addressed are:

- How may the gains in basic skills be made to transfer more effectively to other learning?
- What is the scope for developing an ILS where learning gains go beyond those in basic skills?
- What role might the teacher have in linking the gains in basic skills to the development of problem solving skills?

The remainder of the paper describes and discusses a software development project based at Leicester University which has attempted to find answers to these questions in a niche curriculum context; the curriculum focus is practical science. Although its curricular ambitions are more limited than a full ILS, its development and evaluation provide valuable pointers to how the early promise of ILS may be realized.

The Leicester OILS Project sought to broaden the ILS concept by augmenting the standard software features (curriculum content, student records and management) with four further dimensions relevant to typical practice in the conduct of practical science lessons in secondary schools in the UK:

- Providing interaction with another software program, in this case the Insight data-logging program;
- Making direct links with ‘bench work’ in the science laboratory;
- Building in a role for the teacher; and
- Exploiting pupil-pupil interactions.

Thus the ‘open’ spirit of this approach is to incorporate experiences beyond the confines of the normally self-contained ILS software; some computer-based tasks should stimulate off-computer activity (e.g. prompt questions and discussion
Table 1. Some of the graph tools in Insight data-logging software.

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zoom</td>
<td>To magnify a chosen portion of the graph and rescale the axes.</td>
</tr>
<tr>
<td>Cursors</td>
<td>For obtaining and comparing values from the graph.</td>
</tr>
<tr>
<td>Bar display</td>
<td>To illustrate relative magnitudes of values and rates of change.</td>
</tr>
<tr>
<td>Analyzing aids:</td>
<td>For calculating numerical features of the data from the graph.</td>
</tr>
<tr>
<td>Interval, Ratio, Gradient</td>
<td></td>
</tr>
<tr>
<td>Curve fitting</td>
<td>To identify and describe a trend within discrete measurements.</td>
</tr>
<tr>
<td>Define</td>
<td>For calculating derived data to reveal relationships.</td>
</tr>
</tbody>
</table>

about data), but the software should also generate tasks based on non-computer activity (e.g. the analysis of experimental results obtained in the laboratory). This accords with the most successful reported practices with ILS which is embedded in the curriculum (Brown 1997), involves a clear role for teachers (Spilsbury 1997) and features group rather than individual use (Meverech 1994), themes which will be developed later.

At this stage it is necessary to understand the context of data-logging activity in practical science. This involves obtaining experimental data from sensors and data-loggers which communicate by direct connection with the computer. The acquired data is presented as graphs, and most of the interpretive process focuses on the analysis of these graphs. The data-logging software *Insight* (Logotron 1992) provides a variety of tools (table 1) and techniques which overcome many of the limitations and inaccuracies which students typically show when plotting and analysing graphs manually (see Barton 1997, for a comparative study of pupils' use of manual and computer-aided graphing methods). The main window of the OILS program coexists on the screen as a companion to *Insight* and is published under the name *Understanding Insight* (Logotron 1998). An important role of *Understanding Insight* (*UI*) is to make the student aware of the variety of methods for exploring graphs with *Insight*, give practice in obtaining useful information from them and help them use this to interpret the data.

In keeping with the traditional practice for describing and comparing 'Intelligent Tutoring Systems' (for example, Wood 1998), the design objectives of the OILS program *UI* will be considered under three headings:

- **Knowledge** model, describing the knowledge and skills to be learned;
- **Learner** model, describing the learning process and its organization; and
- **Tutorial** model, describing how the program manages pupils' responses.

**The knowledge model**

Data-logging techniques have widespread application in scientific and industrial research and commerce, ranging from the automatic data gathering in space probes down to the monitoring of frozen food distribution. In education, data-logging has developed as an approach to practical activity on the laboratory and as such it is not confined to certain science topics but finds a wide range of application across the science curriculum (Frost 1993, 1999). It has also been successfully applied throughout all key stages in the school curriculum, which is reflected in the diversity and variety of available software offering colourful graphic representations of data for young pupils through the mathematical curve fitting techniques employed at advanced level and beyond. So the knowledge model for *UI* needs to embrace
generic skills and approaches rather than specific applications. There are four main elements.

*Proficiency in performing data-logging experiments*

Pupils learn how to set up data-logging experiments. This requires familiarity with hardware; sensors and interfaces, and how to connect them together. It also involves integrating the electronic hardware with normal laboratory apparatus.

*Proficiency in operating the software*

Pupils learn how to use the *Insight* software for gathering data and how the graph represents numerical data obtained from experiments. Graphs are manipulated in a variety of ways to expand the information which can be obtained. Several levels of proficiency are identified according to the needs of pupils as they progress through the key stages.

*Techniques for analysing data*

Pupils recognize the shape of the graph as providing useful scientific information. Further quantitative information can be obtained using software tools for measuring features of the graph and for performing calculations. It is necessary to recognize the appropriate tool for the information required and to associate analysis techniques with scientific questions about the data.

*Interpreting data*

Pupils should gain confidence in applying these analysis techniques to help them interpret the data in a way which leads to a better appreciation of the science underpinning the data and to draw scientific conclusions.

*The learner model*

Although it is an important part of the project to promote the development of pupils' skills in 'thoughtful' observation and interpretation of data, it is first necessary to develop a certain threshold of competence in basic skills, and then teach how these may be applied to more 'authentic' problems. To acquire this competence, pupils are taught how to use the software tools with a number of concrete examples using data in a stylized 'tidy' format. The smooth lines and curves of such data allow a clear focus on understanding the tools and avoid distraction from 'noisy' features often present in experimental data. Later, in the application phase, pupils will need to recognize and ask questions about such features. To prepare for this, as pupils practise the basic skills, they are made aware, by example, of the sort of science questions relevant to the tools concerned.

At all stages it is important to ensure frequent interaction with *Insight*. The learning envisaged requires activity rooted within *Insight* so *UI* should not merely function as an explanatory script but should aim to be an interactive companion. To achieve this, the tutorial text is organized into suitable modules with optimal amounts of text appearing on the screen at any one time and frequent prompts for
tasks directly with *Insight*. The text is also designed with due attention to the level of language, specialized vocabulary, layout and visual cues (prototype designs were previously field-tested with 11 and 12 year-old pupils).

In the progression from basic skills through to their application, a hierarchy of skills and required understanding can be identified which implies a preferred sequence of the module pages. However, in the spirit of providing an interactive learning environment, pupils should be allowed to navigate backwards and 'sideways' as well as forwards through these pages. The main purpose of backward navigation is to allow the checking or revision of previous experiences. Similarly, the 'sideways' interactivity with 'help' pages provides opportunities for revision or for checking summaries. A further aspect of interactivity, the need for providing a diagnosis of pupils' errors, is discussed later as part of the tutorial model. An underlying principle is to provide pupils with alternative expressions and representations of the learning issues.

Providing such navigational freedom has its hazards, for it is necessary to acknowledge the natural disposition of pupils to click the computer mouse in a sometimes hasty and arbitrary way. Sometimes rapid clicking is symptomatic of exploring by trial and error and sometimes of simply guessing a response. Haste and guessing are no new problems for teachers to deal with but the ease of clicking accelerates the haste and increases the risk of getting lost down distracting pathways. Therefore the freedom to navigate must be balanced by incentives for pupils to keep on track. This requires the program to make the teaching objectives clear and encourage pupils to commit themselves to thinking and getting correct responses on first attempts. A common example of this in *UI* is where pupils are free to try out various manipulations in *Insight* before they commit themselves in their answers. They can switch between *Insight* and *UI* and go forwards and backwards to check previous tasks and answers. This flexibility has the potential to reduce the risk of forgetting previous issues and encourage experimenting with ideas.

The emphasis on the responsibility and personal response of the pupil implied above is an important feature of constructivist learning theory in science (Driver 1988) which envisages the learner constructing their personal meanings from experience. More recently the contribution of social interaction to the construction process has been emphasized (Driver *et al.* 1994). These factors indicate the need for software features which invite discussion with a partner or a teacher and *UI* seeks to achieve this through prompts to experiment with ideas and by using a variety of styles of question (see the 'Tutorial model' described in the next paragraph). The 'free response' type of question explicitly invites teacher interventions. The ideal response of pupils is one of 'mindful engagement' and although this should be encouraged by confidence from acquired basic skills, there is a potential need for further teacher interventions to help pupils to apply these skills effectively.

**Tutorial model**

This section considers the tasks presented to pupils and how the system responds to them as learners. The tutorial window of *UI* is designed to coexist on the screen with *Insight* and the main components are as follows:
• Eight 'lesson' modules focusing on the acquisition of basic skills (setting up data-logging experiments, manipulating graphs, obtaining information from graphs, interpreting the information to draw scientific conclusions);
• Four 'experiment' modules each giving a framework for conducting an experiment (evaporation, rate of reaction, pendulum motion, electric circuits);
• One module giving guidance on setting up the apparatus and software for an experiment; and
• a help facility which can be accessed at any time.

Each module provides a mixture of information, instruction and testing, and is intended to require between 15 and 25 minutes for completion. The 'lesson' modules are organized in a progression of sophistication from Key Stage 3 to Key Stage 4 requirements. Each 'experiment' module is divided into sections which give the background science, relevant scientific questions, instructions for setting up the experiment, a series of tasks for analysing data, prompts for drawing scientific conclusions and a test exercise with a sample set of data.

Throughout each module pupils are set a succession of tasks and questions. In order to accommodate a range of assessment needs and objectives, five different types of question were designed:

• simple choice — quick spot checks on understanding. Pupils are presented with a simple choice between two alternative answers to the question.
• numerical readout — testing accurate use of cursors and graph analysis tools. Pupils take a reading or find a numerical value from an Insight graph and type it in an entry box.
• multiple statement — requiring the drawing of conclusions from a graph. Pupils are presented with four statements and have to identify each as true or false.
• free response — requiring description, explanation or reasoning. Pupils are required to compose a sentence in response to the question.
• Insight settings — checking correct adherence to instructions for using Insight. Pupils are required to use a specified tool or facility in Insight or manipulate the graph in a prescribed manner.

With the exception of the free response question type, the pupils' response is monitored continuously by the program and errors are reported on the screen immediately. When errors are made on a particular question, advice is given on how to correct the error and pupils are allowed two further attempts before given the correct answer and progression to the next task. At the end of each module the pupil's score is reported as an overall score and as a profile of the skills involved. In the case of free response questions, a model answer is displayed and compared with the pupil's own answer. For these, a mark has to be awarded by the teacher. An overview of each pupil's performance is reported on a dedicated Teachers' Record window. This provides detailed information about pupils' scores for each lesson and their accumulated skills profile.
Development methodology

From the early stages of development a prototype program was tested with Year 8 and Year 9 pupils. During these trials attention was paid to pupils’ responses to several aspects of the text appearing in the UI window: vocabulary, special terminology, language style, optimum amount of text, length of sentences, spacing, layout, format, use of bullets and graphics. All these issues received close scrutiny and through an iterative process the text was modified to achieve a close match with the language commonly experienced by pupils in science lessons. Furthermore, the structure and content of each module was reviewed to ensure that, for most pupils, there was an acceptable balance between the introduction of new ideas, repetition and practice. It was also necessary to ensure that the overall time requirement for a module would not exceed 25 minutes with the majority of pupils.

Evaluation methodology

When completed, Understanding Insight (UI) was tested with six groups of Year 9 pupils working in pairs or trios. All pupils were volunteers who worked on the computers in four lunch-time sessions lasting 45 minutes each, and a fifth session for a semi-structured interview with a researcher. Amongst the total of fourteen pupils there was a good spread of ability and equal numbers of boys and girls. None of the pupils had previous experience of Insight, thus, during the evaluation, UI would carry the main burden of introducing and instructing pupils in the use of the main features of Insight. At the outset the two researchers refrained from giving pupils a detailed explanation of either piece of software save that of outlining their purpose and how to get started. Pupils worked through four basic ‘lesson’ modules and one ‘experiment’ module. For the latter, the activity was mainly focused on analysing previously recorded data rather than setting up apparatus. Pupils were encouraged to alternate in their use of the keyboard and to discuss aloud their ideas prompted by the tasks set within the UI program. During the sessions the researchers adopted a strategy of minimum intervention but kept written notes on the response of pupils and the chief topics of discussion. Each researcher observed the same group for all sessions and in the final session the group was given a semi-structured interview to ascertain their thinking and views on a range of aspects of the software-mediated tasks. Throughout, the focus of observation was broader than operational consideration of software features; for this investigation it was considered important to record observations which would permit reflection on the context in which the software was being used so that a ‘situated’ evaluation could emerge. For each group interview, a common set of 26 questions was used and the responses for all pupils were collated under a number of headings: the scientific context of the data, clarity of explanation of the tasks, the scientific purpose of the analysis performed, the perceived advantages and disadvantages of using the software for analysing graphs, the application of analysis tools in unfamiliar situations, opinions of features which aided or hindered understanding, the pace and sense of progression through the tasks, views on the group mode of working. The collated data from the interviews, together with the written observations from the software sessions, provided a rich but complex resource for study. In view of the ‘open’ approach being pioneered by the OILS project, it was
appropriate to develop an evaluation framework for the data which took account of the chief factors external to the software. In this spirit a 'situated' approach to evaluation was developed.

A 'situated' approach to evaluation

The essence of a situated approach to evaluation is the view that all the components of a learning environment, both people and artefacts, interact and contribute to the learning process (Squires and McDougall 1996). This approach seeks to consider the distribution of intelligence during the classroom use of a piece of software, i.e. the contributions made by the teacher, the student and the software itself. The contribution of the software is effected through the decisions made by its designer. So there are three actors contributing to the situation of a package in an educational setting: two live actors (teacher and student) and one passive actor (designer). An approach to software evaluation which embraces this view is the Perspectives Interactions Paradigm proposed by Squires and McDougall (1996). This consider the interactions between the perspectives of the three actors and provides the main framework for discussing observations in this study. For the purpose of this study, the paradigm has been adapted to include certain aspects of the usability of the software and the tutorial process, which are pertinent to an OILS package. An overview of the evaluation framework is shown in table 2.

Designer–teacher perspectives

The interaction between the designer and teacher perspectives mainly concerns the curriculum relevance of the software. The main question addressed here is 'how

<table>
<thead>
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<th>Table 2. Evaluation framework.</th>
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<tr>
<td>Designer–Teacher perspectives</td>
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<tr>
<td>Knowledge issues</td>
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<tr>
<td>• Explicit curriculum aims</td>
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<td>• Assumptions about previous knowledge</td>
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<td>• Deploying the new skills in wider contexts</td>
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<tr>
<td>Usability issues</td>
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<tr>
<td>• Ease of use</td>
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<td>• Screen layout</td>
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<td>• Use of pictures</td>
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<td>• Language level</td>
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<td>• Amount of text</td>
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<td>• Availability of help</td>
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<tr>
<td>• Step-by-step approach</td>
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<td>• Interactivity</td>
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well does the software match the curriculum requirements in schools? In the case of both Insight and UI software the relevant curriculum aims are embedded in the UK science National Curriculum Orders. For example, under the attainment target ‘Experimental and Investigative Science’, pupils are required to develop their skill and understanding of measurement, recording, graphing, interpreting and evaluating experimental data.

Insight data-logging software was specifically designed to meet these requirements so there is a good match between the designer’s and teachers’ curriculum objectives. Indeed, an important feature of this type of software is that it automates some of the mechanical aspects of data collection thus allowing pupils to invest more time in the interpretative and evaluative aspects of scientific investigation (Newton 1998, Rogers and Wild 1996).

For the UI software the curriculum agenda, as presented previously, has four main elements:

- Proficiency in performing data-logging experiments;
- Proficiency in operating the (Insight) software;
- Techniques for analysing data; and
- Interpreting data.

Again, a good match can be identified with the National Curriculum targets. Apart from the four experiment modules in UI on specific science topics, the generic features of the software allow teachers wide discretion in selecting its context of use in the teaching laboratory. The software design assumed pupils’ previous knowledge of graphs and the Windows user interface, but these were the only necessary assumptions about the Year 9 pupils involved in the evaluation. Thus, having mastered the software, there are potential links with many topics for experimental activity in the UK science curriculum.

In order to realize the potential to support investigative work, UI provides training experiences for pupils which are intended to equip them with skills which can be redeployed in new contexts. Some of the interviews with pupils suggest that this process can take time and can have perhaps unexpected costs. One pupil commented that, with the computer method ‘... you don’t get so much [practical] experience because you are not reading the results and not doing the measurements yourself’. However the same pupil also thought that ‘the computer gives more accurate measurements and better results’. Clearly, it may take time and experience in using software for its relevance to be appreciated by pupils, but here is a potential intervention issue for teachers who could make a point of highlighting the special qualities of the software techniques and suggest further examples of their useful application.

Designer–pupil perspectives

The influence of the software designer is mediated through the use of software itself. As Squires and McDougall (1996) note, although the software designer is not present during its use, the designer’s presence is implicit in the software features. Many design details such as screen layout, use of pictures, level of language, access to help messages, etc., influence the ‘usability’ of the software, but there are other important respects through which the designer’s beliefs about
learning are also manifested in the software. In developing this aspect of evaluation, the designer's model of the learning process comes under scrutiny. In the Perspectives Interactions Paradigm, Squires and McDougall imply that software can support constructivist approaches where the design is such that there is sufficient flexibility in its use for pupils to interact with it reflexively. They suggest that the agenda for evaluating these aspects of software should include its potential for:

- Learner control — to foster ownership;
- Challenge — with intrinsic rewards;
- Scope — developing global versus local skills;
- Complexity — reflecting 'real' as opposed to contrived tasks;
- Exploration — of different problem solving approaches;
- Expression — of pupils' own ideas.

For the present study, this list has been augmented to include consideration of the extent to which the software offers:

- Repetition and reinforcement;
- Flexibility of pace; and
- Differentiation in question style.

These software attributes can contribute to a learning environment which affords pupils the opportunity to make a personal response to it. The extent to which each of these attributes feature in Understanding Insight software is considered next.

**Learner control**

When using **UI**, pupils have a large measure of control of the software. Although the tutorial elements are programmed by the designer, the pupils manage the software by making decisions about pace through the tasks, which can vary according to the demands of the particular components. They can navigate through the software, recapping or using the 'help' facility when necessary.

The types of responses to the software tasks are constrained by the design to five answer formats: simple choice, input of numerical values, tick-box response, free response and **Insight** settings. These answer formats provide some variety but they also represent different levels of demand on the pupils and so contribute to the degree of challenge presented. In interviews, pupils indicated their preference for the questions presented in simple choice format. They liked the free-response items least. As one pupil put it '[it is] possible to interpret the [free response] question in different ways', this was perceived as being 'unfair'. Pupils also remarked that the multiple choice items had to be read carefully and thought about.

**Challenge**

Lessons in **UI** increase in demand as the user works through the software. Later lessons re-employ and re-apply skills learned in earlier ones. This has the potential to build pupils' familiarity and confidence with using the software tools. In the later modules, which are based on 'experiments', pupils need to draw on the range of skills learned in the earlier lessons in order to respond to tasks. Thus, the software design presents a challenging environment, both in terms of a progression
in task demand as the pupils work through the lessons, and in relation to the format and content of questions asked. In interview, one pupil commented that 'you need to take your time and think about the questions; the danger of hurrying and guessing is that you have to do it again, and that slows you down'. The need for this sort of care was often highlighted by the numerical readout questions which demanded full use of the precision available within the software, but readily sacrificed through haste or oversight.

The majority of pupils were well satisfied by their rate of progress and felt motivated by the confidence this built for them. However, some lessons were thought to be less challenging than others; as one pupil put it 'it was too long before it was a challenge'. In the early UI lessons, the focus is on basic software operation. For experienced Windows users, the UI environment may have a familiar feel which, whilst having advantages, can reduce the impact of the new software. This aspect of pupils' response to the software was also evident for some who found the earlier lessons to be a little slow and repetitious.

As the pupils work through the lessons, their responses to software instructions and answers to questions are handled by the software management system. The system provides the users with feedback, allowing several attempts at answering and 'rewarding' a correct response with praise. Incorrect responses or actions are rewarded by invitation for another attempt or, after three failed attempts, advice on what to do next. These rewards contribute a 'game quality' to the software which the pupils enjoyed.

**Scope of the software**

This aspect of evaluation considers the extent to which the function or application of the software can be viewed as context specific (localized) or global. Data-logging software such as Insight can be viewed as supporting global tasks in the sense that it is generic software designed for the purpose of collecting and analysing experimental data for a wide variety of science topics. In contrast, the UI tutorial software is designed to support the specific task of helping users acquire the skills necessary to operate the generic data-logging software. In this sense, UI is localized in scope, but it is possible to argue that, at the level of the individual lessons, UI software supports the acquisition of generic skills of software manipulation and generic approaches to data-logging analysis. These skills are ones which pupils could transfer to any subsequent, and appropriate, data-logging activity. Even within UI itself, skills learned in early lessons are applied to solving problems in later ones, and also in the experiments. Moreover, there can be several approaches to exploring data because of the multiple analytic tools that the Insight software provides. This feature was appreciated by some pupils in interview, for example: 'It [UI] taught us how to use all the options and showed us lots of different ways of getting measurements from the graph; for example "time intervals".' In this sense one can view the UI software as supporting activity of a more global kind.

**Complexity**

Within UI, later lessons pose complex data analysis problems, related to scientific investigations. These problems draw on skills developed in earlier lessons and provide examples of their application. Complexity arises because of the need for
pupils to be able to synthesize explanations by applying their understandings of
science and of analytical strategies to their experimental data. The UI software
presents a limited range of experimental problems, but the principles can be
applied to a further range of real-life scientific problems. This potential can add
to the authenticity of pupils’ experience of using data-logging software.

*Exploration and expression*

Pupils’ ability to freely explore solutions to problems is limited by the constraints
of the software: pupils can only do what the software permits. However, there is an
important respect in which UI can liberate pupils’ self-expression. The software
provides a ‘toolkit’ of data analysis features and some training in problem solving
approaches with the software. There are plenty of alternative software tools, ways
of accessing them and strategies to solving the set problems. The combined effect
is to permit pupils a good degree of freedom in their approach. The ideas for
solving particular problems come from the pupils themselves. Pupils must first
appreciate the problem being posed and then select and apply suitable strategies to
solving the problem, with the support of the software tools. In this sense, the data­
logging software provides considerable scope for pupils’ exploratory activity. Most
pupils found the ‘finding out’ interactive style of the activities interesting and one
pair of pupils comments ‘...[it is] better than boring worksheets which tell you
what to do!’

Reflecting on these learning issues, UI software presents a number of features
which can foster a constructivist approach to its use. The primary purpose of
teaching the skills and strategies required to use data-logging software necessitates
a dedicated design. Nonetheless, within the limitations presented, the software
design exhibits several aspects of the components described by Squires and
McDougall (1996) for a constructivist approach.

*Usability*

In any software evaluation, the design of the user interface comes under close
scrutiny for a variety of practical issues which signal the rapport between the
designer and the end user. How successful is the designer in communicating
ideas to the user and gaining their commitment to the tasks? The sort of issues
involved are partly presentational and partly structural; presentational aspects
such as the clarity and variety of the screen layouts, the use of pictures etc. con­
tribute to the attractiveness of the program, but the design of structural features
such as navigational controls and the methods for entering responses are also
important contributions to the ease of use and understanding of the program.
The UI program gained good recognition from pupils on all these points with
the overall verdict that it was easy to understand what the program was asking and
how to make a response. Pupils thought the amount of text presented in the
window at any one time was about right and the level of language identified closely
with that used in their science lessons. Where less familiar technical terms were
introduced, they were explained either directly or through help notes. The step­by-step approach, whereby the text was regularly interspersed with questions and
activities with Insight, made a varied and interactive experience which found
favour with pupils.
Teacher–pupil perspectives

The interaction between these perspectives considers the impact of the software on the teacher–pupil relationship. The potential for pupils to work individually or in small groups can be expected to change the nature of teacher interactions compared with conventional class settings. What is the new role for the teacher in preparing pupils for the software tasks? What sort of interventions are fruitful during the tasks? How can the computer tasks be linked with off-computer activity? From the pupils' perspective the opportunity to work unaided has both social and pedagogical implications. It is possible to imagine UI being used individually, but in typical classroom situations with computers, pupils are frequently organized into small working groups of two or three individuals. This is driven to some extent by the limited availability of resources, but there is research evidence which points to the benefits of this mode of organization at the computer, because it can encourage educationally valuable interaction between pupils (Mevarech 1994, Underwood and Underwood 1999).

Peer group working

Although, only one person at a time can control the UI software, its use of a large number of questions compared with the provision of information, requires pupils to spend most time manipulating the software tools to find answers. This questioning approach can be a powerful stimulus for discussion between group members as the reasoning and searching for a correct response progresses. In the evaluations, the notion of drawing on fellow pupils for support emerged in a number of pupil groups. Pupils liked small-group modes of working since they could draw on support of their peers; for example, in interview, one pupils said that 'you can swap opinions' when working in a group, and another: 'when you are not sure you can ask your partner'. One pupil also appreciated that group collaboration did not necessarily help to solve problems: 'On your own you are likely to get stuck, of course you can also get stuck together sometimes!'.

Pupil independence

In addition to the software promoting peer group working, some pupils appreciated the 'self-contained' nature of the software. Pupils cited the software 'Help' facility as useful when they got stuck in managing the software. When answering questions involving reading of data values from graphs, the pupils liked the software 'giving the correct value to check' because this approach provided a means of evaluating their own responses. Some appreciated the relative freedom for self-checking, that this feature of the software affords, for example; '...you can realise your own mistake.'. It was also noted by pupils that the software could provide them with help without 'having to bother the teacher'; the internal intelligence not only diagnoses pupils' errors but also offers hints for their correction. In addition, pupils appreciated the facility for referring back to previous answers; the navigational system permitted free access to previously attempted questions. These responses from the pupils could be taken to be indicative of the high degree of autonomy that the UI environment offers to pupils. The value attached by the pupils to the relative freedom of the software environment was further supported.
by the comment from one pupil that 'you could just look to see [what to do]'. This was seen as better than just 'listening to the teacher' or 'reading boring worksheets' and appeared to be a lower risk environment for some because 'the computer won't go mad' at the pupil!

**Teacher interventions**

For teachers using *UI*, their role as an information provider is reduced. This role is assumed by the software in respect of the scientific content of the software and in its mode of operation. However, although *UI* is a largely self-contained package offering pupil independence, its design also contains explicit prompts to pupils to ask the teacher to mark their answers to the free response questions. This feature turns out to be a useful stimulus to talk about data; here is an opportunity for teachers to intervene, prompt discussion and encourage pupils to articulate the meaning in their response. It is further assisted by the provision within the program of model answers which can be compared with pupils' own answers. It can be argued that these features of the software encourage pupils to justify answers through reasoned argument with each other and with the teacher. Pupils engaging in this kind of talk about data are working at the higher levels within experimental and investigative science in the Science National Curriculum. Moreover, they are engaging in the kinds of activity which research into pupils' talk suggests can promote cognitive growth (Alexopoulou and Driver 1996; Mercer 1996).

An important aspect of teacher interventions is that they can reduce the possibility of 'early closure' in the exchanges which sometimes occur in pupils' own discussion, particularly when they are exploring something new. However, there is a balance to be struck between the teacher maximizing what pupils can derive from a particular exchange and the potential risk of the teacher 'taking over' and undermining pupils' personal responsibility for their learning. In the *UI* environment, the number of scheduled interventions never exceeds three per module. Beyond this, the teacher needs to discretely monitor pupils' progress through the computer activity in order to identify appropriate intervention opportunities.

The link between talk and learning has recently become a more prominent focus for research in science education. Within the area of computer-aided graphing, Barton (1998) has highlighted the need for a rethink in the teacher's role in supporting pupils' practical work. Part of this rethink, needs to concern developing teacher's skills in the timing and nature of intervention so that these contribute to dialogic exchange between groups of pupils.

**Off-computer activity**

In the practical laboratory pupils need opportunities to use data-logging methods to collect and analyse experimental data. The essence of data-logging is the integration of 'bench work', involving apparatus and sensors, with the skills of analysis and interpretation on the computer. One of the aims of *UI* software is to develop proficiency in performing data-logging experiments and this supported by the 'experiment' modules which can serve as on-screen worksheets giving pupils directions on how to set up data-logging equipment for experiments. Pupils commented favourably on these instructions, remarking particularly on the interactive features of the screen layouts, the step-by-step approach and the visual cues of photo-
graphic images for checking particular details without worrying the teacher. The 'setting up' screens were seen as 'easier than reading a "method" because it shows you...'. The experiment aspect of UI provides a link between contexts for investigative science (which can involve hypothesizing, planning and to some extent, practical activity, away from the computer) with the on-computer task of data analysis.

**Linking with 'science'**

One of the most challenging aspects of the OILS brief is in designing tasks which teach pupils to think beyond the manipulative activity on the graphs and interpret their meaning in terms of the underlying science. This is addressed most explicitly in the experiment modules which present science questions which depend upon obtaining information from the graph. Pupils had no difficulty in distinguishing these questions from those which focused purely on graph properties, but evidence from the study suggests that pupils' awareness of the importance of recognizing and seeking links with science needs to be supported through teacher interventions. Although the examples given attempt to exemplify good practices in scientific thinking, promoting the vision of their broader application demands the skill of a teacher.

**Summary and conclusions**

The Leicester OILS Project succeeded in broadening the ILS concept through the introduction of four novel aspects: interaction with another piece of software (Insight); making direct links with 'bench work' in the science laboratory; building in a role for the teacher and exploiting pupil-pupil interactions. In the evaluation study an adaptation of the Perspectives Interactions Paradigm was used for generating criteria by which the success of the software may be judged.

From the pupils' perspective, the UI program appeared to communicate ideas well, in terms of presentation and structure. Pupils enjoyed a large measure of control over the software; they were able to work at their own pace, check previous answers, have errors diagnosed, obtain advice when needed and had complete freedom to choose when to switch between the two programs Insight and Understanding Insight. The tasks provided progression from instruction in basic skills through to applying those to analysing real experimental data, and they served as models of good practice which could be applied to practical work across a wide range of science topics. Some tasks required careful attention and precise use of the analysis tools. The more demanding tasks required a synthesis of skill and understanding and made explicit links with the science involved. The plentiful number of alternative strategies on offer encouraged exploratory approaches with the data, supporting constructivist principles. This was further amplified by peer group working, in which many exchanges of ideas were observed.

From a teacher's perspective, the UI program has good potential for training individual pupils up to a productive threshold of skill with Insight, making them ready to put data-logging into practice in the science curriculum. The compatibility of the software with the National Curriculum for science in the UK is secure. The promise of independent working is borne out in this study and many benefits to pupils' learning have been described. However, there remains
a number of aspects to the effectiveness of the learning for which the role of the
teacher cannot be delegated, indeed there are new opportunities to be seized.
Although the teacher is no longer the chief architect and administrator of the
pupils' activity, the traditional teacher roles of enabler, challenger, adviser and
respondents (NCC 1989) are undiminished by the shift in responsibility. The
UI program accommodates this by providing explicit prompts for such interven­
tion which stimulate pupils to articulate the meaning in their responses and justify
their answers through reasoned argument with each other and with the teacher.
Beyond this, unscheduled interventions did not form part of the evaluation study,
but, for further research, reflections on the observations suggest some pretexts for
interventions which might enhance learning outcomes:

- Point out what pupils have learnt already and build upon this, e.g. look for
  further instances and recognize them.
- Highlight the special qualities of the software techniques and suggest
  further examples of their useful application.
- Prompt pupils to make links between observations or some other knowl­
  edge.
- Help to interpret the implications for science and keep the science questions
  to the fore.
- Help to reduce the possibility of 'early closure' of pupils' own discussion.
- Review alternative ways of thinking about a graph feature or behaviour.

Most of these teacher interventions are not exclusive to the use of IT but may be
applied to any teaching context. Indeed, they represent contributions to learning
which are difficult to automate in software. Their effect on the quality of learning
with UI or Insight would be an interesting subject for further research. For many
teachers there are no surprises in this list for they are well rehearsed in conven­
tional teaching scenarios. It is possible that teachers are sometimes distracted from
exercising these skills because of the practical demands being a technical trouble­
shooter in a classroom with IT?

It has been argued that teachers have important roles to play in IT-based
practical work. Although pupils have opportunities to be more self-reliant during
these investigations, teachers provide opportunities for pupils to show their u n d er­
standing and frameworks to support pupils' developing thinking. The various roles
and intervention strategies teachers deploy in lessons become pivotal to securing
the benefits of the data-logging approach.

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‘Developing successful pedagogy with ICT – How are science teachers meeting the challenge?’ (with H. Finlayson)


This paper reports on a broad study of classroom practice in the use of ICT based on lesson evaluation reports from a sample of science teachers who had completed training with the Science Consortium under the NOF funded scheme for developing teachers’ use of ICT in their teaching.
Developing Successful Pedagogy with Information and Communications Technology: how are science teachers meeting the challenge?

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ABSTRACT From the diversity of views on the role of information and communications technology (ICT) in education, this article focuses on ICT as a tool for enhancing learning in the subject-defined context. Drawing from evidence gathered from teachers' evaluations of over 300 lessons taught using ICT, we examine the implementation strategies and teacher variable factors which define the pedagogy of ICT use and contribute to the frequently reported successful lesson outcomes. Teachers' perception of success was largely expressed in terms of achievement of subject learning objectives and suggested criteria strongly rooted in their pedagogy developed with conventional resources. The role of teachers' beliefs in underpinning their professional practice is examined and the tendency towards conservative teaching styles is discussed.

Introduction

The use of information and communications technology (ICT) in education is widely regarded as a good thing. ICT has a pervasive presence in society for which all participating citizens need appropriate skill. Outside the education profession, advocates of ICT argue its importance as a tool for future life, an investment in careers for individuals and contributing to the future prosperity for the country. Within education, ICT is also seen as a tool for assisting and enhancing learning throughout the curriculum. Less widely appreciated is a view of ICT's potential to change ways of learning. Heppell (1993) has described an evolution of views on the role of ICT in education, beginning with ICT as an object of study in its own right, progressing to a
view of ICT as a replacement teacher, then the view of ICT as an exploratory tool for learning and finally as an agent of pedagogical change. At present, all these views prevail in education and, together with views in society at large, there is confusion over what is valued about ICT and confusion about the motives for promoting ICT. Against this background there is inevitable confusion about how successful practice with ICT might be recognised in schools.

We choose here to argue the case for subject learning; i.e. that, for legitimacy in subject lessons, the purpose for ICT is as a tool for enhancing learning in the subject. Embracing Mortimore's definition of pedagogy as 'any conscious activity by one person designed to enhance learning in another' (Mortimore, 1999, p. 17), we recognise that the introduction of ICT in subject teaching will inevitably have an influence on teachers' pedagogy, since, for most teachers, pedagogy is embedded in the subject context. ICT can only have a valid impact if there is school support in developing operational skills and, arguably, information technology (IT) capability (Loveless, 1995). In England and Wales, the National Curriculum sets objectives both for ICT skills in their own right and as a tool for enhancing teaching and learning in subject studies. The appropriate balance between the two, in terms of school-wide policy, departmental responsibility and schemes of work, is left for schools to interpret and decide.

The recent government teacher training initiative (New Opportunities Fund) to promote the use of ICT in education in England and Wales has focused on subject teaching and has attempted to reinforce the idea of pedagogically appropriate use of ICT in subject teaching. Although the initiative as a whole has disappointed some teachers and policy makers (Office for Standards in Education, 2002), there is no doubt that it has been directly responsible for the infusion of ICT into hundreds of thousands of lessons nationwide. In one training course alone, amongst those available from over 40 training providers, teachers have submitted, so far, evaluation reports on 24,000 science lessons with ICT (reported by the Science Consortium, 2003). A significant feature emerging from our research into the teachers' responses to this particular programme is that the vast majority of participating teachers report successful lessons with ICT. In this article we will consider what the results can teach us about an emerging pedagogy of ICT use and the factors which indicate and influence its development for individual teachers. To achieve this we address three questions:

- What constitutes successful use of ICT in subject teaching?
- What teacher actions contribute towards successful ICT sessions?
- What teacher variables are associated with successful ICT?
The Evidence Base for the Study

Our discussion is based on an analysis of lesson reports submitted by a sample of teachers participating in the training programme provided by the Science Consortium. Although the nature and design of the training programme and its contribution to the perceived success in classrooms are beyond the scope of this article, a brief outline of the course provision will be presented to provide a context for our evidence base.

The training provider was committed to developing the integration and use of ICT in science teaching at the secondary level for ages 11-16. During the scheme (September 1999 to March 2003), it trained science teachers in over 1100 secondary schools. The training programme encouraged teachers to participate in an iterative cycle of reflective teaching in their own classrooms, based on a pre-prepared framework of lessons. The course had six modules, each one looking at a different application or way of using ICT for subject teaching. For each module teachers were required to teach one of their normal classes using ICT, and send in a written evaluation of it. All the necessary materials were provided, including software, lesson plans and worksheets, and, within a particular module, a wide range of topic areas and levels of presentation were available to suit the requirements of a range of pupil groups. Each teacher was individually registered and had online contact with a tutor who gave feedback on their evaluations.

There are few large-scale studies reporting ICT developments in normal classroom teaching, and those that have been done often do not give strong support to gains in pupil learning (Watson, 1993). A recent statistical study from the ImpaCT2 series (Harrison et al, 2002) does show that pupils in schools with high ICT use achieved higher than predicted performance in national tests at ages 14 and 16 years, in comparison with those in schools with low ICT use. These findings reached significance only in science, not in other subjects for this age group, but did not go into any detail of how the ICT was used to result in the higher achievement. The nature of the study precluded consideration of the actual types of ICT activity or teachers' contributions to its manner of use. One problem of research in this area identified by McFarlane (2000) is that of trying to use quantitative data (e.g. improved pupil test scores) to measure what many would claim to be qualitative improvements. The anecdotal finding that pupils understand the subject and engage with the problems posed may not be immediately evident from performance in tests demanding principally memory work. Qualitative studies have been criticised for the small numbers of students involved and the special conditions under which they have been carried out, and meta-analyses of such data have found it difficult to draw conclusions from widely varying contexts.

Against this background, the high frequency of reports of apparent success in our data, together with the fact that the data were representative
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of a large-scale exercise in regular classrooms, make the data exceptionally interesting. Although the pro formas for the teachers' evaluations were not specially designed for our study, they provided a unique opportunity to examine a range of factors concerning the implementation, integration and effect of using ICT in subject teaching, as well as considering the changes in teachers' attitudes and behaviour which would indicate a permanent adoption of ICT within their teaching.

The teachers' evaluations were the principal source of data, but we also consulted background school information available through relevant official school inspection reports. A preliminary analysis of the data from a limited number of evaluations was carried out independently by each researcher, using the NVivo qualitative analysis tool. The results were compared and discussed and the exercise repeated to determine the extent, limitations and validity of the data. An agreed coding system was then set up and used to analyse the data in a larger sample of evaluations from 61 teachers in science departments in 11 schools, chosen to represent a spread of different types of school and different geographical areas.

**What Constitutes Successful Use of ICT in Subject Teaching?**

To consider this question, the main problem to address is that of identifying indicators of success with ICT. This is made complicated by the many variables which influence the outcome of ICT in lessons. A significant variable is the diverse readiness of children in classrooms, in terms of their ICT skills (Cuban, 1997). Software design is also clearly a very important factor towards success. The evaluation of software for learning cannot be satisfactorily approached without reference to 'situational' factors which are directly influenced by decisions of teachers as they define lesson objectives and interact with students. Squires & McDougall (1996) argue that the success of software also depends upon the match between the software author's implicit pedagogy and that of the teacher. Evaluation is made further complicated by the fact that often ICT confers advantages which change learning parameters and render tasks with ICT which cannot be directly compared with conventional practice (Hammond, 1994). It appears to be part of the nature of ICT to cause qualitative change to the learning contexts to which it is applied. Noss & Pachler (1999) go as far as to propose that ICT is transforming knowledge and learning to an extent that demands a radical review of present curriculum and methods of teaching and learning.

Since all the teachers involved in our study drew from a common pool of software applications (embracing Internet use, multimedia, data logging, spreadsheets, simulations and presentational tools) carefully chosen by the training provider, the effect of software as a variable is much less significant.
in our data set than differences arising from individual teachers in different schools. The teacher is a key variable which we regard as central to our discussion. The use of ICT cannot succeed on its own merits (Kennewell, 2001), but needs the actions of a teacher. Numerous studies have pointed to the importance of the teacher's role in integrating ICT into classroom teaching (Pedretti et al, 1999), the setting of parameters for learning (Scrimshaw, 1997), the definition and management of appropriate learning objectives (Rogers & Wild, 1996), supporting students with procedural strategies (Jessel, 1997; Smith, 1997) and establishing the norms and culture of the classroom (Olson, 1988).

In our study, relying on the self-evaluations of teachers, 83% of their lessons with ICT were rated as having successfully fulfilled their teaching objectives. A simple analysis of these objectives reveals a high profile for subject-related objectives.

<table>
<thead>
<tr>
<th>Objective type</th>
<th>% of lessons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject knowledge and understanding</td>
<td>85</td>
</tr>
<tr>
<td>Investigation</td>
<td>14.5</td>
</tr>
<tr>
<td>Subject skill or process</td>
<td>12</td>
</tr>
<tr>
<td>ICT skill</td>
<td>18.5</td>
</tr>
<tr>
<td>Research</td>
<td>8</td>
</tr>
<tr>
<td>Revision</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Table I. Types of objectives of lessons.

Clearly, teachers were persuaded of success in terms of the value to their subject teaching rather than the development of ICT skills for their own sake. What factors persuaded teachers of such an impressive level of response?

Gains of quality and efficiency were frequently quoted advantages of ICT use: the speed of access to information, accuracy of data obtained electronically from experiments, speed of calculation of numerical data and the clarity and speed of graphical representation. In the following example, the quality achievable through presentational software appeared to give a boost to the professional self-esteem of the teacher:

The board work was replaced by the presentation. This gave the lesson a much 'slicker' feel to it and removed the pressure from me to be drawing diagrams as I went along. It also provided more impact, partly because I had imported some images into the presentation but also because it has a more professional appearance. The headings and captions provided a tighter framework for discussion.

This type of example resonates with the officially proclaimed benefits of ICT (Department for Education and Employment, 1999), but, more importantly,
such examples are valuable signals of the recognition by teachers of potential benefits to learning. Goodyear (1985) has argued that ICT has substantially reduced the amount of 'inauthentic' labour inherent in data handling activities. In considering supposed advantages of ICT, one must be cautious that they are more than mere restatements of self-evident properties of software. To say that software works quickly, saves time and offers colourful graphics is merely descriptive of software properties and, as Newton & Rogers (2001) point out, learning benefit only accrues from how such properties are employed. We argue that a teacher's recognition of the potential for learning benefit is an important indicator of successful ICT.

Related to the theme of efficiency, the value of software tools for performing difficult or repetitive tasks is a common theme in teachers' comments. For example, the spreadsheet was widely recognised as a versatile calculating tool with benefits for pupils of all abilities. Here it was acknowledged that most pupils reaped the benefit of the program doing the 'hard' work of multiple calculations, achieving accuracy and reliability in the results, whilst more able pupils in particular were extended by the opportunities for prompt reflection on the results and further exploratory thinking:

discussion of results became the principal focus of the activity.

Examples like this also illustrate a change in emphasis, reported by many teachers, from the collection of information towards its analysis, facilitating an investigative approach in which students take a large measure of responsibility for designing activities and asking questions about the results. This concurs with the earlier research of Rogers & Wild (1996), who observed in practical science lessons that the use of ICT and an investigative mode of working were mutually beneficial. Investigative methods of working imply a constructivist teaching approach and research has established a strong compatibility between this and ICT tasks. The major study by Sandholtz et al (1997) of the Apple Classrooms of Tomorrow project in the USA demonstrated how ICT transformed classrooms to become more student centred in teaching approach. Smaller-scale studies in the United Kingdom, such as that of Barton (1997), have also indicated high levels of interaction and engagement fostered in ICT tasks. In our own study, many teachers were enthusiastic about the opportunities for students gaining direct control:

Their learning is increased, as it is the pupils themselves that are able to change the parameters and then see the effect of the change.

The pupils enjoyed the freedom to choose their own activities and the responsibility that came with it and worked hard all day to produce an excellent set of reports and materials.
Thus we would argue that the development of student-centred teaching approaches is a further indicator of success.

The motivation and enthusiasm of pupils has been a strong theme in evaluation studies (Kirkman, 1993; Cox, 1997) and our study shows no signs of this dimming, even as computers become increasingly pervasive in children’s lives. Sandholtz et al (1997) suggest that student enthusiasm is a useful indicator of engagement, along with the extent of voluntary time use, the amount of on-task activity, student initiative and experimentation. All of these factors were indicated in our study, with teachers expressing pleasure with the general quality of engagement of pupils and the high proportion of on-task activity:

I enjoyed the lessons, as did the pupils judging by their enthusiasm and the written work they produced. Many went far beyond the task.

A striking feature of the data was the high frequency of reports which implied teachers’ recognition of ICT making subject knowledge more accessible and improving learning. As previously noted, teachers remarked on the quality of results with data loggers, the labour saving aspects and accuracy and reliability of the recording process, but these software properties were also frequently linked with potential learning gains such as greater clarity of thinking, and encouragement for the interpretation of the results. In particular, real-time data logging, offering the simultaneous presentation of graphs, was seen to be of great value to learning:

It made it very clear to them what was happening because they could actually see it happen rather than them having to read a thermometer, record a set of results and then plot them as well. It added hugely to the learning value of the lesson in my opinion.

Similarly, simulation software, providing opportunities for performing ‘virtual’ experiments, was extremely popular amongst teachers, receiving strong recognition for stimulating thought, clarifying ideas, efficient use of time and pupil motivation in general. Teachers liked the flexibility of such software, which gave a variety of opportunities for pupil involvement and often assisted the visualisation of abstract concepts through the imaginative use of interactive animated graphics. In general, the theme of ICT enhancing thinking skills is well supported in research (Underwood & Underwood, 1990; Knight & Knight, 1995; Chisholm & Wetzel, 1998) and our data indicate much teacher satisfaction in the effect of ICT as a facilitator for thinking:

The fact the results are instantly visible is brilliant because ‘what if?’ becomes ‘yes I was right’ or ‘no, now why not?’ and sends them on a further exploration.
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The Internet has become a ubiquitous feature of ICT use and teachers saw this as a valuable and vast source of contemporary information, offering a global perspective of scientific issues. With the use of suggested lesson plans, access was generally easy and rapid and teachers mentioned numerous cases of high-achieving students being extended.

**What Teacher Actions Contribute towards Successful ICT Sessions?**

Accepting that the teacher has a key role towards the success of ICT, what actions and aspects of that role are needed to realise success? Kennewell has described the teacher as the 'orchestrator' of the influence of ICT on learning in the classroom, bridging the gap between potential and actual activity in lessons (Kennewell, 2001). Loveless et al have argued that the roles of both teachers and learners need to be considered afresh in the new era of the information society brought about by ICT. Ready access to vast amounts of information through ICT has subordinated the role of the teacher as an information provider to one which focuses on how to deal with information in ways which enhance learning (Loveless et al, 2001, pp. 67-72). In part this involves identifying new teaching strategies but it also requires recognition of aspects of skill which do not need to change. If the former pose challenges, the latter should offer reassurance to teachers.

It is clear from our study that many established teaching skills not only retain a vital role in classrooms with ICT, but require reassertion in the wake of the additional technical demands of ICT. These involve planning and organisation as well as skills of instruction, communication and intervention.

The importance of clear teaching objectives was a significant message from teachers in our study. In particular, there was strong advocacy of tight definition of tasks involving the use of the Internet. In relation to this, many teachers recognised the delicate balance between the advantages of giving students responsibility and the potential unproductiveness of random 'surfing' on the Internet. Successful solutions often involved limited ranges of website addresses, clear deadlines and encouragement to students to develop their critical skills about the nature and quality of information obtained. In formulating such strategies, some teachers were explicit about being influenced by the perceived ability of their students:

> I would also restrict access to a particular area of a site electronically with weaker students. The process of browsing/surfing detracts from learning with all but the most able.

For all types of ICT activity, Table I shows that by far the majority of stated objectives reflected subject teaching ambitions, with less than one-fifth of
DEVELOPING SUCCESSFUL PEDAGOGY

lessons including the development or exercise of ICT skills as an objective. Where there was confusion in the priority of subject or ICT development, lesson outcomes tended to be less satisfactory. Sometimes teachers recognised that ICT offered opportunities for new objectives or widened access to familiar ones:

ICT provided access to information for those pupils who might otherwise have had difficulties because of SEN [special educational needs], they may have found it difficult to use an index but could use a search engine with ease.

Careful preparation by teachers for lessons with ICT brought due reward. This may seem a trivial observation; however, reports contained a few examples of poor preparation, for reasons which were unclear, but with the inevitable consequence of an unsatisfactory lesson. Our analysis showed the importance of preparation in which teachers not only rehearsed the use of software but considered the skills requirement for the proposed activity and defined tasks to match students' needs. Other issues include choosing the method of starting the lesson (e.g. discussion, theory or demonstration), and designing or adapting worksheets to provide differentiation.

I prepared a worksheet in advance which contained step by step instructions on how to access the site. I also gave the pupils specific questions to answer in order to reduce browsing. I also allocated a particular planet to each group (3-4 pupils) to avoid information overload.

Teachers' expectations for the manner of engagement of students frequently emphasised thinking and discussion. They often saw an important aspect of their own role in providing a framework for prompting students' thinking; for example, in promoting the 'observe, predict and test' cycle in practical work, in linking or comparing the activity with conventional non-ICT methods or previous learning, or in making comparisons between different sets of information. Indeed, during a practical science experiment, discussion between students and teacher did not interrupt the recording process which proceeded automatically under software control:

Whilst circulating, I was able to draw individual groups' attention to the emerging graph and to pose questions about what might be happening, thereby guiding them to ideas later expressed during the debriefing session.

Further aspects of teachers' pedagogical skill are decisions about lesson formats and classroom arrangements. Choices they make about whole-class activity, groupwork, or use of the computer suite by individuals, and so on, have a profound effect on the manner of engagement of students. When a
demonstration format was used exclusively, the most commonly declared reasons were logistical constraints: the non-availability of a heavily booked computer suite, or simply the lack of computers or peripheral equipment in sufficient quantity. Teachers were creative in optimising hands-on experience for students through asking them to help with teacher demonstrations, organising them to work through a circus of different activities, or by organising a split class rota. Each organisational format has implications for the interaction between students and teachers and students with each other. All of these organisational devices were in evidence in our study, but, as Table II shows, the type of software used also influenced the choice of teaching format.

<table>
<thead>
<tr>
<th>Type of activity</th>
<th>Individual (%)</th>
<th>Group (%)</th>
<th>Teacher demonstration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internet</td>
<td>46</td>
<td>44</td>
<td>10</td>
</tr>
<tr>
<td>Data logging</td>
<td>2</td>
<td>33</td>
<td>65</td>
</tr>
<tr>
<td>Simulation</td>
<td>19</td>
<td>13</td>
<td>68</td>
</tr>
<tr>
<td>Spreadsheet</td>
<td>39</td>
<td>39</td>
<td>22</td>
</tr>
<tr>
<td>Using models</td>
<td>30</td>
<td>38</td>
<td>32</td>
</tr>
</tbody>
</table>

Table II. Comparison of teaching formats for different ICT activities (n = 207).

Research has highlighted the value of student collaboration. Indeed, there is clear evidence that working in small groups at the computer is more beneficial to learning than individual use (Underwood & Underwood, 1990, pp. 156-161). Groupwork not only facilitates the sharing of ideas, it provides opportunities for students to explain and have ideas validated as they help each other. These are the conditions for peer tutoring, reported and advocated by Sandholtz et al (1997) for developing a culture which gives students a sense of ownership of the learning process. Our study yielded an example of a teacher deliberately exploiting this mode of working as a method of learning:

one pupil was able to explain to their partner what they were doing and why. This was in evidence early in the lesson, so I decided to encourage this and to introduce it to other groups; a couple of pupils were surprisingly effective in this role and were obviously empowered by the activity.

Such implicit acknowledgement of students’ expertise and the encouragement of mutual help can have a profound positive effect on the motivation and achievement of students (Sandholtz et al, 1997). It has been further observed that when teachers overtly learn alongside and from ‘expert’ students, the process of integrating the use of ICT into classroom settings gathers pace (Hruskocy et al, 2000). The nature of students’
expertise with computers is worth considering a little; for most student
experts, their skill tends to be of an operational and technical kind which is
qualitatively different from and complementary to the subject-related skills of
the teacher. So, far from being rendered redundant by student expertise, the
teacher still retains an important pedagogical role. Loveless et al (2001)
have suggested that constructing knowledge from information requires more
than the ability to use a variety of ICT techniques but also embraces an
ability to question, access, interpret, amend and analyse information
(Loveless et al, 2001, p. 67). This in essence is the concept of 'IT capability'
and the teacher should be in a strong position to take a lead in helping
students to develop this broader skill.

Although research gives strong advocacy to groupwork with computers, studies also indicate caution about the conditions which favour
success. In particular, groups must have the ability to organise themselves in
ways which integrate the contributions of all members. This demands a
certain maturity in students managing the task requirements and resources
on their own and the social skills to share and negotiate ideas and roles
(Hoyles et al, 1994). Here again there is an important role for teachers, both
in structuring the tasks and in organising and managing productive
groupings. This is a familiar requirement to teachers, as represented in this
element:

The children worked in pairs chosen by me with the intentions that
their working habits and skills would be complementary.

Further affirmation of familiar teaching skills comes from the frequent
references in teachers' reports to making links with previous work, setting
targets, giving instructions, deciding when to intervene, giving the right sort
and amount of help, prompting discussion, asking questions to probe
understanding, sharing ideas, issuing reminders and summarising what has
been learned, and so on. It is also evident that ICT provided opportunities
for enhancing such skills. For example, in giving instructions, it was still
necessary to do this orally or with a whiteboard, overhead projector or
worksheet, but it was also possible to use PowerPoint or web pages with
direct hyperlinks to further resources. Teachers report creative ways in
using the 'time bonus' of software; giving additional help to weaker pupils,
sharing results, prompting analysis and discussion, and generally
emphasising thinking about the interpretation of results.

The use of a model allowed me to spend more time, with the weaker
student, whilst those that had a good understanding could extend their
knowledge by exploring new situations.
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What Teacher Variables are Associated with Successful ICT?

Mumtaz (2000) has observed that the teacher is one of three interlocking factors that influence teachers' use of ICT, along with the institution and resources. Here we shall explore those individual variables which inform teachers' attitudes towards ICT and the choices that they make about their methodology in the classroom. We believe that our data offer glimpses of teachers' beliefs through studying their opinions and choices. We can also observe connections between variables but will be cautious about drawing conclusions about causal relationships.

Teachers' Beliefs

Recognising that teachers carry frontline responsibility for classroom practice, it is fair to begin our discussion by empathising with their viewpoint. Experienced teachers have well-established beliefs about what constitutes successful lessons and learning and they are entitled to ask what ICT contributes to enhance the quality of lessons and learning (Cuban, 1997). When teachers appear not to embrace the vision of ICT, there is likely to be a variety of explanations.

Rejection is sometimes the inevitable result of lack of teacher time for learning how to use ICT or the lack of supporting networks in schools for teachers with low confidence in their ICT skills (Dupagne & Krendl, 1992; Winnans & Brown, 1992; Rosen & Weil, 1995). Dawes (1999) argues that teachers make rational choices in terms of their beliefs and that poor uptake is due to ICT not being 'selected' as much as advocates of new technology would hope.

The manifestation of teachers' beliefs about learning is to be found in a range of attributes and actions observable in everyday professional practice. In each case, teachers' beliefs are implicit in their attitudes, preferences and choices:

- Expectations and beliefs about pupils' abilities (What are appropriate levels of conceptual demand, pace and language? Should students be organised in mixed-ability groupings or setted in order of ability?).
- Choice of objectives when designing tasks (What is the balance of emphasis between process skills and subject content?).
- Assumptions about the teacher's role in the classroom (Is the teacher a knowledge provider or a facilitator, interpreter and guide?).
- Teaching style (Is this characterised as didactic [telling] or investigative [finding out]? How much teacher-student interaction is used? Does questioning technique empathise with students' view?).
- Management style (What principles underpin control and discipline: rules, flexibility, student autonomy, recognition of student expertise?).

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Teaching format (When should students work individually, in small groups or be taught as a whole class?).

In the context of the classroom, a teacher's personal pedagogy may be thought of as a synthesis of their positions on each of these issues.

As our discussion explores the connection between pedagogy and ICT, it must recognise the need to acknowledge the roles of culture, beliefs, representations of subject knowledge, learning environment and interactions between learners and teachers (Loveless et al, 2001, p. 67). The study of teachers' use of ICT by Moseley & Higgins (1999) has established significant connections with their subject knowledge and pedagogy. For example, those with belief in pupil empowerment tended to use small-group work and easily adapted this approach to teaching with ICT. They provided good ICT opportunities for their pupils in both quantity and quality. Teachers who preferred whole-class teaching often did not have such advanced personal skills and confidence in ICT. They saw computer work as an opportunity for pupils to work individually, but did not value this greatly. They made fewer opportunities for pupils to use ICT, and tended to use less complex software (Moseley & Higgins, 1999).

Teaching Styles

In our study, the teaching materials available to teachers could be used in a number of different teaching formats. Most programs could be demonstrated to the whole class, particularly when the school had a data projector or interactive whiteboard. Similarly, most applications could be used by small groups, or by individuals, if the schools had sufficient facilities. Many teachers showed a preference either for whole-class teaching or for small-group work in most of their lessons. Sometimes this was constrained in practice by the computing facilities available at the time of their lessons, but usually teachers clearly stated when this was the case:

If a computer room had been available then I do think the pupils would have got more out of it.

Ideally I would have liked the pupils to have attempted the activity in small groups on their own machines, but timetabling did not allow this to happen.

The teachers who showed a preference for whole-class teaching generally chose to use a demonstration technique with software. Such lessons were often very successful, particularly with the visualisation software simulating scientific phenomena, when the teachers could feel in control of the pace of the lesson. However, when the same teachers allowed students to use computers, usually for the information gathering tasks, as with the study of
Moseley & Higgins (1999), they tended to set students working individually, rather than in pairs or small groups. This was less successful when many individuals required technical assistance at the same time:

Not all can log on and be served quickly therefore some students found connection very slow.

Many teachers learned to accommodate their teaching styles to make the best use of the facilities available. Several teachers in well-equipped departments developed a hybrid approach, introducing the software and subject matter to the pupils through demonstration, then allowing them to work in small groups or individually with worksheets, to develop their own understanding.

In our previous discussion of teachers' actions contributing to successful ICT lessons, we noted the desire of many teachers to encourage students to think and their welcome of increased opportunities afforded in software for promoting thinking. Associated with this was the value placed on the role of discussion in helping students gain understanding:

The model (using just the data projector) allowed for good whole class discussion as the simulation occurred - lots of thinking on feet for us all!

Pupils were easy to engage in conversation about a dry science topic because they wanted to make the simulation work. This small group discussion is a powerful teaching method and not that easy to achieve.

Investigative approaches were implied in many teachers' descriptions of student activity and teacher interventions:

Pupils are able to investigate a wider range of questions in a shorter period of time. Their AT 1 [investigation] skills are improved, allowing them to think more independently.

These examples serve to illustrate teachers' engagement with process skills which, according to Scrimshaw (1997), need to be made central elements of a successful curriculum with ICT.

For most experienced teachers, their beliefs about learning and consequent pedagogy are well established before involvement with ICT. A stable equilibrium exists in which the prevailing curriculum, familiar teaching tools and teachers' beliefs refined through experience inform their teaching methods. However, the introduction of new tools, such as those provided by ICT, challenges their existing beliefs (Finlayson & Perry, 1995) and poses questions about their methodology (Solomon, 1986). When a teacher innovates with a new teaching tool, it is natural to adapt its use to the old methods. From the perspective of maintaining self-esteem, teachers
are likely to adopt strategies which either preserve or enhance their role, but if the new tool threatens their influence, they will adopt protective practices which unfortunately can also limit the potential of ICT (Olson, 1981).

Conclusions

For the majority of teachers in our sample, successful ICT was clearly rated in terms of subject teaching objectives: more than four-fifths of lesson evaluations explicitly indicated teachers' satisfaction that lesson objectives were fulfilled. Table III summarises their views on these successful outcomes and the roles they played in achieving them.

<table>
<thead>
<tr>
<th>Successful outcomes reported by teachers</th>
<th>Number of reports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesson objectives successfully achieved</td>
<td>83% (n = 244)</td>
</tr>
<tr>
<td>Views on advantages of ICT</td>
<td></td>
</tr>
<tr>
<td>Potential for clarifying subject matter and promoting thinking</td>
<td>70% (n = 218)</td>
</tr>
<tr>
<td>Saves time and labour</td>
<td>51% (n = 218)</td>
</tr>
<tr>
<td>Greater ease of use over traditional methods</td>
<td>31% (n = 218)</td>
</tr>
<tr>
<td>Potential for improved quality of students' work</td>
<td>23% (n = 218)</td>
</tr>
<tr>
<td>Scope for special stimulus to students both of high and low ability</td>
<td>17% (n = 218)</td>
</tr>
<tr>
<td>Teachers' role</td>
<td></td>
</tr>
<tr>
<td>Plenary role with the whole class, demonstrating software, giving instructions or making links between activities and previous knowledge</td>
<td>42% (n = 213)</td>
</tr>
<tr>
<td>Circulating around the class, giving subject-related help, guidance and support according to need</td>
<td>42% (n = 213)</td>
</tr>
<tr>
<td>Asking questions, prompting discussion and probing students' thinking</td>
<td>38% (n = 213)</td>
</tr>
<tr>
<td>Technical troubleshooting and ICT operational help</td>
<td>12% (n = 213)</td>
</tr>
<tr>
<td>Students' responses and achievements</td>
<td></td>
</tr>
<tr>
<td>Good understanding of and thinking about the subject matter</td>
<td>41% (n = 244)</td>
</tr>
<tr>
<td>Enjoyment, interest and motivation</td>
<td>38% (n = 244)</td>
</tr>
<tr>
<td>Extending the most able and supporting the least able</td>
<td>18% (n = 244)</td>
</tr>
</tbody>
</table>

Table III. Teachers' views on successful outcomes of lessons.

Only one in six reports indicated negative effects on students' achievements. The motivational effect of ICT is likely to have been a persuading factor towards teachers' feelings of success in lessons and in general the character of their comments about students' achievements indicated criteria which were essentially rooted in their existing pedagogy.
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We have argued that a teacher's recognition of the potential for learning benefit is an important indicator of successful ICT. This was indicated, not only in teachers' perceptions of students' achievements, but also in their views expressed on the advantages of ICT exemplified in their reported lessons or as visions for future lessons. It should be noted that the pro forma used for teachers' evaluations avoided prompting specific issues for mention as advantages or disadvantages. Teachers' ideas arose in a voluntary manner, thus the results reflect their own values and concerns. It is significant that the topics of concern are strongly focused on teaching and learning. A high frequency of reports implied teachers' recognition that ICT made subject knowledge more accessible, stimulated thought and improved learning. Even the references to time saving frequently stressed pedagogical benefits such as the stimulus of instant response, the reduction of inauthentic labour and the scope for discussion, interpretation and differentiated help.

Our previous discussion examined the importance of the role of the teacher in influencing the outcomes of lessons with ICT and portrayed a range of valuable teacher interventions. The incidence of technical troubleshooting and ICT operational help was relatively low, occurring in less than one-eighth of reports. Taken as a whole, the data show that teachers had a strong organising presence in the classroom, establishing attitudes, defining tasks, selecting lesson formats, setting targets, monitoring progress and so on. These teacher actions appear to be just as necessary for nurturing the success of ICT as they are in conventional situations.

For the majority of teachers, success with ICT was founded on adapting the use of ICT tools to match their existing pedagogy. As Table II shows, teacher demonstration, groupwork and individual work are each well represented as teaching strategies, suggesting a partial but good presence of student-centred methods. Further research should seek to identify innovation in teaching methodology prompted by the unique features of software.

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References


Laurence Rogers & Helen Finlayson


This paper is an interim report on the Classroom Observation Project, focusing mainly on the pilot study in preparation for the main project.
The quality of data analysis in practical activity in science is related to the quality of observation and physical measurement and the method of displaying the measurements. New tools based on Information Technology can contribute greatly to this quality and give greater depth of learning. Joint research at Leicester and Loughborough universities, in association with three schools, is trying to quantify the 'value' of IT to practical science.

INTRODUCTION

Analysis of numerical data is fundamental to practical activity in science. The quality of analysis relates closely to the quality of observation and physical measurement and the method of displaying the measurements. The tools used for measurement have been undergoing major changes with the advance of technology, with instruments requiring a high level of skill being superceded by ones much simpler to use.

The most recent advances in computer hardware and software have now provided tools which can immediately provide a quality of data display with a consequent immediacy of analysis being available to the pupil. This closely parallels the advantages of word processors in providing the ability to separate out the creativity of writing from the mechanics of writing. Data-logging equipment is now so highly developed and easy to use that pupils need only take decisions about which sensors are to be used and when to start logging.

The quality of data is assured once the (properly designed) experiment is running and the attention of the pupils on the problem under investigation can be maximised. There is also the added advantage that the promptness of display provides many opportunities to set new hypotheses and alter conditions to carry out a new test, thus giving greater learning depth from investigations.

If data logging offers so many advantages for practical work, why are so few science departments in schools implementing its use. Are the supposed advantages recognized by teachers? In a recent survey by the National Council for Educational Technology [1] it was reported that, although a large number of schools use some IT applications in science, the actual amount of time per pupil is small. In the case of data logging, only 11% of schools used it for more than 3 hours a year, 54% made some use, and 35% reported no use at all. The commonly cited reason for this is a lack of resources, and this was recognized by HMI [2] when they wrote: 'A problem in the recent past has been the dearth of easily used sensing equipment and software, but
the position is changing'.

However, even one computer and data-logger in a laboratory would give more use than the NCET evaluation report indicates. The report went on to say that 'Often competence in IT is developed through a need for its use. It is hoped that, if teachers benefit from the use of IT they will see the value in the pupils doing the same and apply the practice in their teaching'[1]. Perhaps a prerequisite of persuading teachers that there are benefits to be gained is to identify clearly the value of IT to pupils' experience of science?

The research reported in this article is a pilot study of how this value might be identified and possibly quantified when IT is used in practical science. Observations were made so that the performance of pupils using IT could be compared with pupils using conventional methods.

THE STUDY SCHOOLS AND TOPICS

The study was conducted over a period of nine months in three schools:

A 11-16 Grant maintained
B 14-18 LEA school
C 11-18 City technology college

Classes and topics were chosen in such a way that work could fit into the curriculum with minimum disruption to the normal routine. The topics of linear motion, the weather, electricity and Sci1 investigations were covered in year 8 to year 10.

STUDY METHODS

The three schools provided contrasting approaches to the organization of classes for the comparison between IT-based and non-IT based work.

Class divided into two halves:
1 using IT
2 conventional approach

Two parallel classes:
1 using IT as part of a circus
2 conventional approach

Selected groups:
1 using IT
2 conventional approach

The work was supported at schools A and B by student teachers. Supply cover was available for teachers to attend planning and review meetings, prepare materials and provide classroom support. Observation schedules were used by observers in some classes to monitor the type of pupil activity on a time interval basis. Pre-test, post-test, exam results and comparison of test results and nature of answers were used to try to assess any differences between groups in this first phase of the work.

OBSERVED EFFECTS OF USING IT MEASURING TECHNIQUES

School A
A year 10 group was split into four equal groups (based on previous exam results) for work on the effects of mass and force on acceleration, two being taught by a PGCE student using IT (light gates and timing software) and two taught by the normal class teacher using ticker-tape. The IT groups scored an average of 82% on the topic test as opposed to 74% for the ticker-tape groups. The IT groups were observed by a researcher. It was noted that the pupils approached the equipment hesitantly but once started they quickly collected data, looking at the data as it was collected and carrying out many repeat measurements on their own initiative. When asked if they would do so many measurements using ticker-tape they said not because of the time problem in calculating results and 'messing around with bits of tape'.

Two year 9 classes of similar ability were being introduced to distance-time and speed-time graphs. One group used the motion sensor with the BBC computer, plotting distance-time graphs, as part of a circus; the other groups just used more conventional experiments such as rolling balls. During the lessons, timed observations by a researcher gave some indication that pupils' quantitative analysis of the data was developing at a much earlier stage in the lesson, with such discussion starting in the first 10 minutes when using the IT as opposed to the later half of the lesson without any IT facilities.
The use of IT in practical science

(a) Used motion sensor

(i) Motion of a car

![Graph showing motion of a car over time.]

(ii) Motion of a bouncing ball

![Graph showing motion of a bouncing ball over time.]

(b) Did not use motion sensor

![Graph showing motion of a car and bouncing ball over time.]

Both classes were set homeworks and a later test to assess understanding. In this case the marks were in favour of the non-IT group (63% to 57% for homework and 70% to 59% for the test). However, the quality of graphical answers showed a difference not taken into account by the mark scheme, in the more realistic nature of the lines from those who had used the motion sensor (Figure 1).

School B

A circuit experiment employing previous knowledge was set up to span one double lesson. 24 year 10 pupils were selected in groups of 3 from 2 classes:

4 IT groups (BBC computer + current-voltage box)

4 non-IT groups (circuit with conventional meters)

The pupils were judged to be of similar ability, having been selected on the basis of their previous exam performances. The lesson was organized in a pre-test, practical activity, post-test format with the pre-test and post-test asking exactly the same questions but with different data provided. The differences between the results of the IT and non-IT groups were inconclusive. There appeared to be two main reasons for this outcome.

First, the IT groups appeared to be disadvantaged by the fact that this exercise was their first experience of using the computer kit, whereas all pupils had previous experience of setting up circuits using conventional meters.

Secondly, it was realized again that the tests were designed in a way which did not allow for, or reward, changes in learning possible with the IT; they were conceived in the context of conventional laboratory work. In the case of this electrical experiment, pupils using the computer could see the shape and steepness of the graph on the computer screen straight away; they could ‘play’ with the data using the cursors, taking readings and making comparisons directly. These were the qualities of the IT method which were not rewarded by the tests used.

To obtain better ‘value’ from the IT method, we suggest that the teacher needs a strategy to exploit these qualities of the IT method; eg, deliberately encouraging pupils to ‘play’ with and analyse the data, giving them ideas for doing this.

These problems highlight the researcher’s difficulty of trying to measure change in pupils’ performance over a short timescale.
and show the necessity of a threshold of experience with IT needed for pupils to compete on an equal footing with conventional methodology in this quest for hard data.

A second strand to the study within this school involved a Sc1 investigation spanning three one hour lessons on the topic of motion: 'What factors affect the speed of a bicycle freewheeling down a hill. Investigate two possible factors.' This again involved Year 10 pupils working in groups of about three. The pupils were given a free choice of measurement apparatus including a BBC computer, light gates and timing software. The investigation was organized on the basis of:

1 hour planning
1 hour carry out investigation in small groups
1 hour individual write-up and evaluation.

The investigation reports of pupils from eight classes were marked and scrutinised for methodology. Ten pupils were selected on the basis of some interesting aspect of their report and interviewed to find out how they made decisions about their method and the reasons for their choices.

Pupils' reasons for choosing the computer for measurement included:

1 The computer was thought to give more accurate results with a better precision (could measure short-time intervals).
2 Were able to take lots of measurements to check accuracy.
3 Used the computer to calculate (velocity) as well as measure (time).
4 Pupils had seen the teacher demonstrate computer measurement.
5 'does not give 'funny' results as the digital clocks sometimes do.'
6 Thought that manual measurements would take longer.

Some of the reasons given by pupils who did not choose the computer:

1 Not confident in using computer. Thought digital timer was easier.
2 Told by teacher to use digital clock and light gate.
3 Not enough computers; had to queue and wait for turn.
4 Never seen computer used for measurement.

When questioned on the time needed for measurement activity the responses included:

Overall, the computer method needed more time because of the queuing caused by the shortage of computers. Pupils tended to take more readings than non-IT users.

(In a teacher's view, the volume of measurements needed by the class was only possible through the use of IT.)

Closer scrutiny of the experimental technique showed that:

1 The average of four measurements was usually taken largely because it was a well rehearsed technique for most pupils.
2 The averaging facility within the software was not used due to lack of awareness of the software facilities by teachers and pupils.

School C

A module of work for a year 9 class on the topic of 'Weather' spanned 10 lessons which included 3 featuring the possible use of the computer. The class of 23 was split into six groups; three groups used IT and three used conventional measuring/recording techniques involving thermometers. All pupils worked within the same lab with the same teacher and all were already very conversant with the use of computers. Pupils were expected to boot up the software and connect and check the data loggers and sensors for correct working.

The lessons were conducted in a style which placed great emphasis on pupils designing and conducting investigations to find answers to questions or problems posed by the teacher. Pupils were observed to be extremely confident in this method of working and the collaboration within groups was of a high quality. Thus all pupils were well 'in tune' with an investigative and collaborative approach to practical work, but the use of observation schedules showed
that, (compared with non-IT groups) IT groups:

1. Spent more time discussing variable and describing data obtained.
2. Moved on to discussion and extension questions sooner in lessons.
3. Spent less time in actually gathering data.
4. Spent more time 'playing' with data.
5. Obtained much better quality graphs, as shown clearly in Figure 2.
6. Were not inhibited in the use of the software or hardware.

**Figure 2** Comparison of graphs for evaporating liquids
All pupils were set three tests devoted to the analysis of graphs in which the average scores of the IT groups was 66% compared with 56% for the non-IT groups.

In this school, teachers reported that IT had proved to be a valuable tool for promoting an investigative approach, since it freed pupils from repetitive measurements to concentrate on the design and evaluation of experiments. One teacher commented that 'IT guarantees getting results'.

TEACHERS' VIEWS

During the researchers' visits to the participating schools, and during joint planning and review meetings, teachers made many comments relating to the advantages they had observed through using IT for measurement and recording during practical activities. Other points came up more generally from discussion. It is worth documenting these unsolicited comments.

Pupils did significantly better when interpreting graphs.

The immediacy of the graph provides a medium for talking about science.

Using IT moves pupils up the Sc1 levels immediately because of the quality of data.

There is a guaranteed outcome if thought is put into content and objectives for the use of IT.

The quality of the data gives the pupils a better chance.

I found the motion sensor to be particularly useful. (PGCE student)

Such comments suggest that the teachers saw many positive aspects to using IT in practical science work which would eventually make a positive contribution to their teaching and the pupils' learning. Reflecting on the experiences in the three schools, there was a consensus that the following were essential conditions for 'successful' IT-based lessons:

1 Confidence of teacher.
2 Quality software (easy to understand and use).
3 Reliable sensors (when the signals are noisy or intermittent, pupils can be misled).
4 Standard connections (achieved by using a single type of hardware).
5 Clear system for organization of equipment in the laboratory (storage and distribution of data-logging kit and computer stations).
6 Time for teacher and technician to supervise and maintain the IT kit.
7 Training of the technician to gain understanding of IT requirements.
8 A whole school policy so that pupils have complementary IT experiences across the curriculum.

DISCUSSION

This study provided many positive indicators of the value of IT in practical science, but it also raised serious questions about the research methods employed and suggested several lines for future inquiry.

Research methods

The study suffered from two major difficulties in attempts to measure the difference in the achievement of the two groups of pupils. First, there was the short timescale of observations. Attempting to observe the incremental effect of one, two or, at the most, five lessons proved inconclusive. The influence of IT, as a single factor, was well outnumbered by the many other experiences which contribute to the quality of children's learning.

If IT has a positive influence, perhaps it is only discernible when the learning environment is rich in IT and sustained over a period of time? Secondly, most of the written tests used for measuring pupils' achievement tended to be insensitive to the effect of IT experiences; the interesting exception occurred in school C.

The post-test used in this school sought to exercise pupils' skills of graphical interpretation, skills which are plentifully employed when using data-logging software.

In contrast, the tests employed in schools A and B were of the traditional knowledge and understanding style, and as such were thought to be biased towards traditional methods of practical work. For future research, more work needs to be done in devising tests which have a broader focus
so that due credit is given to the experiences gained from IT.

**Investigative activity**

The most positive effects for IT indicated by the study mainly relate to the character of pupils' activity rather than measures of their achievement. Observation schedules showed that IT was of significant benefit to an investigative style of working, supporting the assertion that ‘the learning potential... stems from what pupils can do for themselves in an exploratory and investigative mode’ [3].

Pupils spent more time on discussing their results and moved to this stage sooner in the lesson. They spent less time in actually gathering data, but more time exploring the data and trying variants of the experiment. The quality of the graphs obtained with the computer was of a demonstrable better quality, and it is likely that this factor made a significant contribution to encouraging discussion and exploration.

**Pupils' views**

Of the pupils interviewed, many expressed the opinion that the computer offered a means of making high quality measurements. Their criteria for recognizing this quality needs to be scrutinized cautiously; for example some had reasoned that taking the average of a large number of readings with a computer gave accurate results, or that the smoothness of a graph indicated a superior form of measurement, but one suspects that for many pupils, the basis of their belief was rooted more in awe for the high technology rather than a scientific rationale.

**Lesson objectives and styles of teaching**

It was reported above that pupils using computers had, compared with their non-IT counterparts, been observed to spend more time discussing their results. It needs to be noted that the use of IT alone could not assure this; the teacher had a crucial role in developing pupils' skill in order to discuss effectively. The software merely provides the tool for prompting discussion and inquiry; the teacher can develop this through setting suitable lesson objectives and adopting a style of teaching which empowers pupils to ask the sort of questions which helps them explore their ideas.

In several lessons observed in the study, pupils were given a positive strategy for conducting investigations through:

1. The teacher's skill in posing questions but not pre-empting answers.
2. The use of an outline worksheet providing a clear framework for drafting the plan for the investigation and monitoring the development and progress of ideas.
3. The fostering of a class atmosphere in which pupils were encouraged to take responsibility for their work.

Thus, the effective exploitation of the opportunities afforded with IT depends upon the teacher adopting positive strategies. When successful, the emphasis may be shifted away from the performance of the more mundane tasks of laboratory work towards encouraging pupils to test and extend their understanding of the science involved. To achieve this, lesson time needs to be devoted to developing the new skills employing IT, and sometimes the objectives will have to be based on learning these skills, in the same way that ‘reading a thermometer’ is a prerequisite of some traditional laboratory work.

Software provides many opportunities for pupils to develop data analysis skills through ‘playing’ with the software functions, such as zooming in on graphs, reading off data points and fitting lines to the points. This will only be achieved with a good working knowledge of the software to use it to its full potential. However, with well-designed software, the amount of time actually needed to achieve an efficiency threshold can be quite modest. The study showed that many pupils became uninhibited in the use of the software and hardware after about only two lessons.

The combined recording and analysing process available through IT makes the ‘method - results - conclusions’ progression into a cyclical rather than the traditional linear process, and in the same amount of time more productive science thinking can
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The present study showed evidence for this process through pupil discussion but also identified the importance of the role of the teacher in choosing suitable teaching strategies which successfully incorporate the use of IT.

REFERENCES


L Rogers is a Lecturer in Physics Education at Leicester University. He has worked for many years on developing the use of IT in practical science and designed many data logging devices and associated software to support the use of IT in science.

P Wild is a Lecturer in Science Education and Information Technology Coordinator in the Education Department at Loughborough University, with research interests in the effective use of IT in the school curriculum and management.
‘Does ICT in science work in the classroom? Part 1, The individual teacher experience’ (with H. Finlayson)

School Science Review (2003) 84 (309) 105-111

This article is a partial report on the study of classroom practice in the use of ICT based on lesson evaluation reports from a sample of science teachers who had completed training with the Science Consortium under the NOF funded scheme for developing teachers’ use of ICT in their teaching.
Does ICT in science really work in the classroom?
Part 1, The individual teacher experience
Laurence Rogers and Helen Finlayson

ICT can make valuable contributions to the quality of teaching and learning in science, but teaching skills have an important role in translating the promise into reality.

Despite the UK Government's recent emphasis on new technology and education, and a history of over 20 years of developing ICT for the classroom, the overall picture of ICT in science teaching (Ofsted, 2002) shows that what is actually happening on a daily basis varies greatly from one school to another.

One of the most recent initiatives, the ICT training funded by the New Opportunities Fund (NOF), focuses attention on to the integration of ICT into the teaching methodology of each subject. Although the initiative as a whole has disappointed some teachers and administrators, there is no doubt that it has been directly responsible for the infusion of ICT into tens of thousands of lessons nationwide. In the Science Consortium programme alone, teachers have submitted, so far, evaluation reports on 24,000 science lessons with ICT. In this and a subsequent article we seek to distil some of the useful practical experience expressed by teachers in a representative sample of such reports. The results are based on an analysis of 350 lesson reports submitted by a sample of ten secondary schools engaged in the Science Consortium programme.

ABSTRACT
This article reports on the experience of teachers from ten different secondary schools using ICT in science lessons, when participating in the Science Consortium NOF training. It discusses the teachers' views of the materials they used, the problems and advantages of using the different applications, and the necessary conditions they reported for successful teaching outcomes.

Resources for teaching science with ICT

Software uses in science can be broadly classified into six different types of science learning activity:

- Information gathering - using Internet browsers and multimedia CD-ROMs.
- Practical work - using sensors, interfaces and datalogging software.
- Simulations - virtual experiments and visual aids, simulating and helping to explain phenomena.
- Data-handling - using spreadsheets and graphing software to analyse data.
- Use of mathematical models - exploring relationships, predicting and testing theories.
- Communication - publishing, record-keeping, PowerPoint, web-page authoring.

Some types of activity are served by generic content-free software such as spreadsheets, whilst certain activities, such as simulations, require purpose-designed context-specific software. Both types of software have their advantages and disadvantages; for example, topic-specific simulation software often proves to be very efficient in demonstrating with great clarity a physical phenomenon or process, but the
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process of acquiring skill and confidence with the software can be frustrating if the design of the software requires idiosyncratic operation. This is less likely if the software conforms strictly to Windows style conventions. Teachers in our sample found the simulations provided by the Science Consortium from the Multimedia Science School extremely user-friendly in this respect:

The dedicated software package ... is much more convenient and meant that pupils would be able to obtain graphs of relationships without needing to know how to manipulate [the software].

Of all the categories of activity listed above, simulations attracted the largest number of favourable comments with 95 per cent of teachers reporting that their teaching objectives of lessons with this type of software were successfully achieved.

Generic software, such as word-processors, web-browsers and spreadsheets, has the great advantage of permitting economy in training investment. Once acquired, skill in using such software can be applied over and over again in a wide variety of different contexts. Many teachers reported that pupils are well equipped with such skills before they enter the science classroom. These were skills awaiting exploitation in science lessons.

An important aspect of generic software is that, being content-free, it does not imply a purpose or manner of use, but demands curriculum context, scientific ideas, data or software file templates to make it ready for action in the classroom. Teaching objectives are the key in defining these factors. In their reports, all teachers in our sample declared the learning objectives for their lessons with ICT: Table 1 gives a profile of these objectives, classified by type. Many lessons specified more than one type of objective.

An interesting feature of these data is the dominance of 'normal' science teaching objectives, suggesting that in general ICT facilitated science learning rather than displacing it. Taken together with the fact that, overall, teachers rated 92 per cent of their lessons with ICT as having successfully fulfilled their objectives, this indicates that an impressive majority of lessons were deemed successful from the point of view of learning science:

I did not need to teach the pupils any extra ICT skills, the emphasis of the lesson was science and the IT did not compromise this in any way.

Table 1 Objectives of lessons classified by type.

<table>
<thead>
<tr>
<th>Objective type</th>
<th>% of lessons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science knowledge and understanding</td>
<td>85</td>
</tr>
<tr>
<td>Investigation</td>
<td>14.5</td>
</tr>
<tr>
<td>Science skill/process</td>
<td>12</td>
</tr>
<tr>
<td>ICT skill</td>
<td>18.5</td>
</tr>
<tr>
<td>Research</td>
<td>8</td>
</tr>
<tr>
<td>Revision</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Pupils’ proficiency with ICT skills acquired outside science lessons was frequently reported:

A lot of the pupils continue to surprise me with how much ability they do have with a computer. They tried with enthusiasm and most did ask for help if needed.

The motivation of pupils in using computers implied here was also much reported.

The role of the teacher

There were numerous references in teachers’ reports to the exercise of familiar teaching skills that are commonplace in conventional lessons. For example:

- making links with previous work, setting targets,
- giving instructions, deciding when to intervene, giving the right sort and amount of help, prompting discussion, asking questions to probe understanding, sharing ideas, issuing reminders and summarising what has been learned, and so on:

  with appropriate intervention and questioning, pupils were prompted to consider the facts in context, e.g. surface temperature compared with Earth.

Less visible, but no less important, are those traditional planning skills that are needed in advance of any lesson, whatever the topic or method: assessing the skills requirement for the proposed activity, defining tasks, matching a task to pupils’ needs, choosing the method of starting the lesson (e.g. discussion, theory or demonstration), designing worksheets, providing differentiation. For example, for a lesson with the Internet in which pupils acquired information about the planets:

I prepared a worksheet in advance which contained step-by-step instructions on how to access the site. I also gave the pupils specific
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Questions to answer in order to reduce browsing. I also allocated a particular planet to each group (3–4 pupils) to avoid information overload.

Similarly, references to the management of lessons indicated several aspects of conventional teacher activity. For example, getting pupils to help with demonstrations, organising a circus of activities, organising a split class rota, circulating around pupil groups.

The importance of traditional teaching skills is not diminished by the incorporation of ICT activity into the lesson. The aura of the computer suite, bristling with high technology, and the protocols for operating computer equipment may suggest a learning environment with different pedagogical norms from the normal classroom or science lab, but the evidence from teachers indicated the relevance of, and need for, much conventional teaching skill. Contrary to the view of some educational administrators, computers cannot do the teaching on their own, they are merely tools for teaching. Teachers indicated a variety of ways in which they felt that ICT enhanced certain aspects of their skill and methods of working. In particular:

- The program allowed me to monitor all pupils at the same time. I could ask questions at will. Move and check note taking. I could adapt, speed up or slow the lesson as I observed progress.

- The board work was replaced by the presentation. This gave the lesson a much 'slicker' feel to it and removed the pressure from me to be drawing diagrams as I went along. It also provided more impact, partly because I had imported some images into the presentation but also because it has a more professional appearance. The headings and captions provided a tighter framework for discussion.

- The datalogger enabled much more to be done in the lesson – it freed me from a demonstration and pupils spent more time on their activity.

Some teachers described how ICT facilitated new ways of carrying out tasks that would otherwise be laborious or impossible using conventional methods. For example, graphing software offers a variety of interactive methods of exploring numerical data:

- The actual task of describing trends was greatly facilitated by the ability to plot graphs quickly and this was especially useful for the less able.

The more able were encouraged to investigate trends and relationships which would not normally be considered due to the amount of time that would be required to plot the necessary graphs.

Datalogging methods create new opportunities for performing experiments over very short or long periods of time: short experiments on transient phenomena lasting just a few seconds, or long experiments extending beyond normal lesson and school hours.

With information-handling software, the potential for teamwork and pupils sharing information can be enhanced:

- My role became much easier as more than one pupil can access the same information at the same time: they tend to encourage each other to look at something new one of them has found. This does not happen with a library.

Classroom arrangements

Most teachers held the view that pupils derive more benefit from working at computers themselves rather than watching a demonstration. The most commonly offered reason was that the first-hand experience was better for gaining skill and understanding. However, Table 2 shows how commonly demonstration, rather than individual or group work, was used as the teaching format.

<table>
<thead>
<tr>
<th>Type of activity</th>
<th>Individual (%)</th>
<th>Group (%)</th>
<th>Demonstration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internet</td>
<td>46</td>
<td>44</td>
<td>10</td>
</tr>
<tr>
<td>Datalogging</td>
<td>2</td>
<td>33</td>
<td>65</td>
</tr>
<tr>
<td>Simulation</td>
<td>19</td>
<td>13</td>
<td>68</td>
</tr>
<tr>
<td>Spreadsheet</td>
<td>39</td>
<td>39</td>
<td>22</td>
</tr>
<tr>
<td>Using models</td>
<td>30</td>
<td>38</td>
<td>32</td>
</tr>
</tbody>
</table>

Some teachers mixed demonstration with group work in the same lesson, particularly when data projectors and large screens were available, but when a demonstration format was used exclusively, the most commonly declared reasons were logistical constraints, the non-availability of a heavily booked...
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computer suite, or simply the lack of computers or peripheral equipment in sufficient quantity. Perhaps unsurprisingly, datalogging lessons were more commonly conducted through demonstration, and here many teachers wished for class sets of equipment. However, teachers devised a number of ingenious arrangements to overcome limited quantities of datalogging equipment:

When only one set of datalogging equipment was available, it was sometimes used in parallel with group activity using the conventional method. Often, pupils' results would be compared with the datalogging results and the qualities of new and old methods discussed.

A single datalogging experiment would be one of a number of different experiments organised as a circus, or available as an ancillary activity servicing pupils' paper-based work or conventional practical work.

When the datalogging experiment was quick, pupils' work was organised in a rota to give each group an opportunity to obtain their own results.

Dataloggers were used in the science lab to collect the data and then pupils transferred to the computer suite to download the data and analyse it on the computers. Variants of this approach sometimes split the class in two halves so that a shift system of working was employed, or sometimes the collecting and analysing activities were spread over two lessons.

Different types of software lend themselves to different class arrangements, with Internet searching and use of spreadsheets heading the list for individualised or small-group activity. One could have expected simulations to be well suited to small-group work, but Table 2 shows that the majority of teachers chose to use demonstrations for this type of application. It could be that for many teachers, demonstration was a well-practised skill with which they felt comfortable; it fed their confidence and allowed them to remain firmly in control. Simulation software was a popular demonstration tool with teachers, allowing them to stage-manage the flow of ideas and whole-class interactions:

*The ICT used in this lesson meant that I could control the information that the students needed to achieve the lesson objectives. I was able to cover quickly some of the simpler parts of the lesson and spend longer on the more difficult areas.*

Individual computer use was sometimes impeded by time-consuming technical issues: the time for logging on, the slowness of the networked computers and queues for printing off individual sets of results.

What did pupils and teachers achieve?

A recurrent theme in reports is the motivation and enthusiasm of pupils. In group work, teachers were pleased with the general quality of engagement of pupils and the high proportion of on-task activity:

*I enjoyed the lessons, as did the pupils judging by their enthusiasm and the written work they produced. Many went far beyond the task.*

In teacher-led lessons, software presentations on a large screen often held pupils' attention and prompted good responses.

There were many instances of improved quality of pupils' thinking, albeit encouraged by teachers but facilitated by software qualities such as visualisation of abstract concepts, speed of access to information, accuracy of data, speed of calculation and graphical representation. Also cited were the benefits to lower ability and SEN pupils of the use of images, sound-clips, accurate calculation tools, automatic graph-plotting and labour-saving text-handling tools. A 'time bonus', whereby software facilitated the rapid or automatic performance of a task, allowed pupils to repeat, revise or extend the task. This was often reported with datalogging and data-handling (spreadsheet) software. Teachers also frequently recognised that whilst using ICT they had more time to give attention to the lower achieving pupils:

*The use of a model allowed me to spend more time with the weaker students, whilst those that had a good understanding could extend their knowledge by exploring new situations.*

The results for each type of software activity are summarised below.

Internet and multimedia

Although the Internet and multimedia CD-ROMs are quite distinctive sources of information, they bear a strong similarity in their methodology of use: navigating the information base, extracting, selecting, and evaluating information. Activities involving information searches with these media required careful planning in order to achieve the intended learning objectives. The majority of teachers reported
the importance of tightly defined tasks with clear deadlines. This theme extended to the selection of websites, which needed to be scrutinised in advance for the level of language use and information content. Teachers recognised the benefits of giving pupils responsibility in their searches, but emphasised the concurrent need to develop their critical skills in relation to the integrity of sources and validity of content. Despite the apparent independence of pupils’ activity in Internet lessons, there were still valuable pedagogical roles for teachers to perform. For example, teachers forged links between the products of Internet searches and other class activities before, during and after the computer-based lesson.

The Internet was seen as a valuable and vast source of contemporary information, offering a global perspective. Access was easy and rapid and teachers mentioned numerous cases of high-achieving pupils being extended. Lower ability pupils needed more structured support, but sometimes pupils could be organised to support each other:

\[ \text{The children worked in pairs chosen by me with the intentions that their working habits and skills would be complementary.} \]

**Datalogging**

Two-thirds of lessons with a datalogger were demonstrations but, despite the low proportion of hands-on lessons, overall teachers’ enthusiasm for the benefits of datalogging to learning science was considerable. Many highlighted the quality of results, the accuracy and reliability of recording, the labour-saving aspects of the logging process and the contribution these make to the clarity of thinking about and interpretation of the results. In particular, real-time logging was highly valued because the graphs could be presented simultaneously with the data-collection process:

\[ \text{It made it very clear to them what was happening because they could actually see it happen rather than them having to read a thermometer, record a set of results and then plot them as well. It added hugely to the learning value of the lesson in my opinion.} \]

The time saved, compared with hand-drawn graphs, was seen as an advantage as it left more time for completing conventional activities and encouraged more focused observation during the experiment. There was a change in emphasis from collecting data to interpreting data that facilitated an investigative approach. Teachers welcomed this, remarking that they could spend more time prompting pupils’ thinking and encouraging discussion about the experiment and the data collected. Indeed, during an experiment, discussion between pupils and teacher did not interrupt the recording process, which proceeded automatically. The role of the teacher was all-important in providing a framework for scientific thinking; for example, promoting the ‘observe, predict and test’ cycle, linking or comparing the activity with conventional methods or previous learning, or comparing graphs of simultaneous data sets:

\[ \text{The ability to do the four reactions simultaneously allowed time for detailed teaching of the way to control the concentration of the reactions as well as a comparison of the rates of reaction and an explanation at the end.} \]

**Simulations**

Simulation software, providing opportunities for performing ‘virtual’ experiments, was extremely popular amongst teachers, receiving high marks for stimulating thought, clarifying ideas, efficient use of time and pupil motivation in general. Teachers liked the flexibility of such software, which gave a variety of opportunities for pupil involvement, often helping to make abstract concepts real through the imaginative use of interactive animated graphics. It was recognised that, as a substitute for laboratory ‘hands-on’ practical work, the advantages of low cost, convenience and guaranteed safety were slightly offset by the lack of opportunity to develop pupils’ awareness of safety. Many teachers regarded simulations as amplifiers of real laboratory exercises rather than as substitutes for them. As with other types of ICT lesson, many teachers underlined the importance of identifying clear lesson objectives and linking the activity where possible with conventional tasks. An investigative approach to task design, in which pupils were encouraged to make predictions and then use the software to test them, was often cited as a successful teaching strategy:

\[ \text{The fact the results are instantly visible is brilliant because ‘what if?’ becomes ‘yes I was right’ or ‘no, now why not?’ and sends them on a further exploration.} \]

**Spreadsheets**

The spreadsheet was widely recognised as a versatile calculating tool with benefits for pupils of all abilities.
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Examples of activities reported by teachers include ‘projectile motion’, ‘diet analysis’ and ‘exploration of planetary data’. In these cases pupils worked on pre-prepared spreadsheets containing all the necessary data. Most pupils reaped the benefit of the program doing the ‘hard’ work of multiple calculations, achieving accuracy and reliability in the results, but more-able pupils in particular were extended by the opportunities for prompt reflection on the results and further exploratory thinking. Again, in many of the successful lessons, teachers reported creative ways they had used the ‘time bonus’: sharing results, prompting analysis and discussion, and generally emphasising the interpretation of results with associated thinking about the science:

Discussion of results became the principal focus of the activity.

Modelling

Modelling activities using software rich in animated graphics were reported to be very successful in engaging pupils’ commitment, building their confidence in working independently and at their own pace. Many teachers were enthusiastic about modelling as an amplifier of understanding. The aspect of pupils being in control of the software-based scenario was considered to be an important encouragement to their thinking. Again, teachers sought to encourage discussion and frequently reported that clear understanding was achieved. However, teachers recognised that adequate preparation was needed for pupils to take control effectively; this not only entailed operational training with the software, but often making explicit links between the model and reality. The complementary nature of modelling tools was reflected in the sometimes reported ambition of teachers to integrate modelling with other ICT applications:

This [model] would be a suitable activity to go alongside a pure datalogging approach.

Enhancement and challenge

A recurrent theme in this article has been the continued role of familiar skills of the teacher, but it is clearly evident that ICT also provided opportunities for enhancing such skills. For example, in giving instructions, it was still necessary to do this orally or with a whiteboard, OHP or worksheet, but it was also possible to use PowerPoint or web-pages with direct hyperlinks to further resources. Many teachers derived great satisfaction from the manner in which ICT enhanced their whole-class teaching role through the use of slide shows with a data projector. PowerPoint presentations and datalogging demonstrations.

However, the new context inevitably posed new challenges. Lesson planning often required a re-think of teaching objectives to exploit new opportunities and to obtain a satisfactory balance between science learning objectives and ICT training objectives. In a minority of teachers’ reports we detected confusion between these two sets of objectives. This was sometimes accompanied by a misplaced expectation that ICT could work unaided, without pedagogical guidance. However, many examples of successful learning indicated the teachers’ recognition of their role and the need for subtle adaptation such as: a change of emphasis in teaching style towards pupil autonomy; exploiting opportunities that facilitated more investigative thinking, discussion and interpretation of results rather than the mere gathering of results; a general change from the teacher as a transmitter of knowledge to the teacher as a facilitator of learning.

Challenges to lesson management arose as teachers attempted to cope with either generous or scant provision of hardware; managing with a limited number of computers demanded organisational skill and patience, but management of a suite of computers required no less skill! Manufacturers and publishers make frequent claims of ‘user-friendliness’, but technology can create a frustrating distraction when equipment or software ceases to behave in the expected manner. It is heartening that only a small number of teachers in our sample reported serious technical difficulties. Confidence to engage in trouble-shooting was often borne of hard-won experience and careful preparation. Some teachers succeeded by exploiting pupils’ proficiency in technical skills, learning from them and facilitating pupils’ self-esteem rather than being daunted by their prowess.

Conclusions

The overwhelming number of positive experiences reported in our sample suggest a resounding affirmative to the effect of ICT on science in practice. Significantly, the results support and amplify the findings of previous research (for example, Rogers and Wild, 1996) in highlighting the importance of the teacher’s role in determining the effectiveness of ICT.
in science lessons. In particular, our study found that successful lessons with ICT were associated with the following pedagogic skills:

- Lesson objectives are clearly identified and tasks are clearly defined.
- The 'time bonus' is used creatively, often involving interventions to encourage discussion and investigative approaches.

ICT activities are explicitly linked to other activities before, during and after the ICT lesson. Teachers plan a greater emphasis on interpretation of results and thinking about science. Teachers recognise and build upon the technical skill already acquired by pupils.

References


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Helen Finlayson is a senior researcher at Sheffield Hallam University. E-mail: h.m.finlayson@shu.ac.uk
This book identifies a range of pedagogical issues which teachers should consider when planning the use of ICT in science lessons. In Part 2 the arguments are analysed and discussed in detail through a series of case studies, each focused on a different science teaching context.
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To enable readers to explore further the examples contained in the case studies, the accompanying CD contains all the featured files together with a comprehensive collection of movies illustrating their use.
Preface

This book is about teaching secondary science using information and communication technology (ICT). Despite the intrinsic attractions of ICT and its high profile in contemporary education, we believe its use in science classrooms should be driven by the needs of learners and the purposes of teachers. For this reason, we have retained a strong focus on teaching and learning in science in the discussion of ICT.

The ideas presented are the result of the authors' many years experience of science teaching and a long-standing commitment to the potential contribution of ICT to this endeavour. This commitment has been realized, for one author, through a long history of development of practical and innovative ICT tools; and an active interest for both authors in researching and promoting the benefits that ICT offers in everyday science classrooms.

It is intended to provide food for thought and practical examples of the potential that ICT offers to science teachers, and to their pupils learning science. To this end the book is organized in three parts.

Part 1 takes a reflective approach to the development of ICT in science teaching. Its three chapters consider how the current context has been shaped by past experience; what educational research has to say about the impact of ICT, particularly for science learners; and how the needs of the science curriculum and active approaches to teaching it present an agenda to which ICT can make a valuable contribution.

Part 2 explores the ways in which a wide range of ICT can be applied in secondary science teaching. Here we consider the features of software and the benefits that these can bring to learners in science. We offer detailed discussion on what science teachers need to understand and be able to do in order to achieve these benefits in their lessons. This discussion is exemplified through short illustrative case studies set in the range of science subject disciplines, which offer practical insights into the issues raised.

Part 3 assesses the role of the science teacher using ICT. It asserts the importance of the teacher's role in planning and implementing learning experiences that are guided by the needs of learners. The reader is invited to reflect on the discussion, which argues that the teacher's role is undiminished by the new opportunities presented by ICT.
Part 1

Information and Communications Technology and science education

Introduction

This part of the book aims to provide the reader with background information to aid understanding of the application of ICT to secondary science teaching. It addresses three aspects of understanding which underpin much of the discussion in the second part of the book.

Chapter 1 traces the development of computer use in science in order to show how we arrived at the present context of ICT use. Change is a dominant theme in contemporary education and a consideration of background context helps to identify 'change issues' which face those who want more fully to exploit new technology for science teaching.

Chapter 2 presents a discussion of aspects of educational research that have a direct bearing on science teaching. This chapter places a strong emphasis on the impact of ICT and on its potential to support science learners.

The nature of the science curriculum and the opportunities it presents for making use of ICT in enquiry and practical activities is considered in Chapter 3. The roles of teachers as designers of pupils' learning experiences and of the learners themselves are discussed, and the benefits of active learning approaches in science are identified.
Chapter 1

Computer technology and the needs of teachers and learners

Whichever way we view the development of ICT in education we cannot escape the dominant theme of change. Whether the changes are rapid or gradual, it is important to attempt an understanding of the nature of such changes, what factors have driven them in the past and what control is possible and necessary in the present. The significance of such an understanding lies in the fact that developments in computer technology enable changes in teaching and learning methods, so a perspective of change is necessary if science teachers are to exploit fully the potential of ICT in their teaching and to contribute to its further development. The purpose of this opening chapter is to help build this understanding by exploring these factors for change. There are two strands to this exploration: issues related to the nature of the technology itself and issues concerning teaching and learning.

**Hardware and software development**

During the past two decades there has been a dramatic contrast between the rapid change of computer technology and the apparent slow change in its application to education. It is comparatively easy to trace impressive developments in computer technology. Previous to 1980 the physical size of computers was typically measured in 'wardrobe' units which were usually the exclusive preserve of large industrial organizations, government authorities and universities. Early educational excursions with computers involved the tedium of posting punched cards to a computer 'at County Hall'; then came telephone-linked terminals which provided a measure of interactivity, albeit laboriously, with a remote computer. This was the scene of the first experiments with science teaching software which attempted to harness the calculating power of the computer to perform the numerous calculations demanded by mathematical models simulating the behaviour of physical systems such as the motion of planets or molecules. Graphical output was limited to crude printouts on teletype paper. Nevertheless, these early applications recognized a useful teaching potential in the computer, in this case exploiting its quality as a sophisticated and versatile calculator.

The invention of the microcomputer with cathode ray monitor, which was compact enough to sit on a desk or laboratory bench, soon enhanced the quality of
output and breadth of applications in education in the early 1980s. Science education was an early beneficiary of the microcomputer since there were numerous examples of applications that could exploit the calculating and graphical facilities. In the UK, the advent of the BBC Microcomputer brought about a revolution in vision for the use of computers in education. This computer offered fast processing and colour graphics at a price schools could afford. More importantly it offered unprecedented accessibility to novice users and fledgling programmers. Many teachers mastered the BBC BASIC language and a host of cottage industries sprung up across the country creating educational software. For science teachers the BBC Microcomputer offered a further bonus, an ‘analogue port’ which could readily be put to use for measurements in the school laboratory. Coupled with rudimentary sensors, it became possible to measure temperature, light, motion and voltage, etc. with a precision and repetition only possible hitherto with expensive laboratory instruments, well beyond the limits of school budgets. With this facility, data-logging in science education was born.

Since the arrival of the early microcomputers, we have witnessed a constant stream of technical improvements in performance concurrently with falling prices. Increased processor frequency has made processing much faster, more plentiful memory has contributed to vastly improved graphics, and the reduced pixel size in monitors has produced high-definition images and high-density text display. The range and variety of peripheral hardware also continues to expand (for example, printers, scanners, video cameras, fax modems, etc.), connectivity between computers gathers sophistication (networks) and communication technology (using optical fibres) continues to increase in capacity.

Box 1.1 Comparison of computer performance

<table>
<thead>
<tr>
<th></th>
<th>BBC Microcomputer (c.1980)</th>
<th>Pentium PC (c.2000)</th>
<th>Increase in performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor frequency</td>
<td>2 MHz</td>
<td>1000 MHz</td>
<td>× 500</td>
</tr>
<tr>
<td>Memory</td>
<td>32 kb</td>
<td>128 Mb</td>
<td>× 4000</td>
</tr>
<tr>
<td>Disc storage</td>
<td>400 kb</td>
<td>30 Gb</td>
<td>× 75,000</td>
</tr>
<tr>
<td>Display</td>
<td>8 colours</td>
<td>16 million colours</td>
<td>× 2,000,000</td>
</tr>
</tbody>
</table>

Burgeoning hardware technology is useless without accompanying software, and the area of software design has also seen similar huge advances which match hardware progress. Software developments have not simply provided more sophisticated functionality, more importantly they have lowered the skill threshold for effective use, thus providing access for a much wider range of users. This has facilitated a welcome transformation from earlier days when computer users tended to be an exclusive clique of ‘gatekeepers’ with jealously guarded secret codes and protocols which protected computer use. Advances in the speed and memory of computers have facilitated the development of the ‘Windows’ graphical user interface which now provides almost universal access for all potential users. The alacrity with which children become competent Windows users is a testament to the maturity and significance of this development.
Schools and ICT

Such innovation in hardware and software technology may be amazing, but the concurrent innovation and pressures for change in education are far more complex and less easily described. Expectations, instruments of law, management reforms, changing trends in pedagogy have all contributed to change and the effects on ICT development in schools show great variation nationally (OFSTED, 1999). There is diversity and sometimes conflict of expectations of what ICT can achieve in education amongst pupils, parents, governors, head teachers, teachers, inspectors and LEA advisers. This is overlaid with a succession of national initiatives for ICT, new management and organisational structures for schools and an underlying trend in teaching style, shifting the emphasis away from didacticism towards the empowerment of individual learners. Thus, it should be no surprise that a complex picture for ICT in schools emerges. Not all these factors can be explored here, but it is appropriate to reflect that the reasons for the slow progress of ICT in education are many and complex, so that it is unlikely that a single strategy for remedial action can be found; it is more appropriate to consider a variety of strategies. In this book we shall attempt to identify general principles which should inform such strategies. In some instances external changes harmonize with and facilitate the progress of ICT; for example, a general shift towards a pupil-centred teaching philosophy facilitates ICT use. This theme will be developed in the next two chapters.

The hazards of technical innovation

Although the progress of hardware technology has been rapid, at each stage of development there have been significant obstacles to innovation in education. Early microcomputers required considerable specialized knowledge and patience to make the systems operational for class use. The physical installation of computer hardware and peripherals was too often constrained by a multiplicity of wire connections and special settings of switches. The complexity of connecting together the hardware components and running the gauntlet of fragile plugs, sockets and possibly defective leads was a considerable hurdle to the computer novice. Loading programs from cassette recorders was a hazardous and tedious process until floppy discs and drives became available. Even then the labour of loading programs from floppy discs before each lesson and the hazard of corrupted and mislaid discs contributed an unacceptable additional overhead on normal lesson preparation and management concerns. Now that hard drives and local networks are the most common methods of storing programs and data, the inconvenience of getting started with programs has mercifully diminished. The installation of new equipment has also become so much more straightforward through the ‘plug and play’ concept. However, before such developments, the survival of a teacher’s commitment to computers necessitated developing confidence as a troubleshooter and in this context computers became the preserve of dedicated technophiles. The obstacles were compounded by the existence of several hardware systems or ‘platforms’ (BBC, Commodore, Mac, PC, Acorn), each with their proprietary specialized technical knowledge with limited transferability.

The performance of computer hardware has clearly had a great influence on the
Teaching Science with ICT

adoption of computer technology, but it can be argued that the software is of far greater importance in conferring usefulness to the technology and defining its role in education as well as in other spheres of use. It is software which enables the computer to perform useful tasks and it is through software that the user interacts with and operates the computer. So the design of software has a crucial role in giving access to computers and unlocking their potential as useful tools. Unfortunately, early software tended to present too many 'gateways' which could only be passed by careful typing. Some computers required the entry of special start-up codes to begin a computer session. A notable exception to this was the BBC Microcomputer which merely required the pressing of two keys to boot up and run a program. Too often, however, users had to endure testing and hostile software environments which made heavy demands on keyboard skills. Programs which required the typing of whole word commands or which possessed an intolerance of the slightest typing error not only tested the patience of the user but could also obscure or invalidate the purpose of the task. The importance of reducing the time burden of operational aspects of software to facilitate thinking and learning is a theme which will be developed in Chapter 2. Generally speaking, the most successful software has embraced the principle that 'error mode is normal mode' when a response is required from the user. Software that demands perfect responses is destined to cause frustration and repel the user. Fortunately a variety of design approaches have accumulated which improve the precision of software operation; for example: an insensitivity to upper and lower case letters, key-letter instead of whole-word entry, drop-down menus with highlighted selection of options. The adoption of the mouse as an input device permitted a great leap in reducing dependency on keyboard skill and paved the way to the graphical user interface of Windows. Much of the power of this user interface is the economy of learning effort resulting from a whole series of conventions which prevail across the range of program applications using the interface. Designers of programs using Windows are required to comply with a 'style guide' which ensures standard methods, procedures and symbols. This is a really valuable aspect of modern software which ensures the transferability of operating skills from one program to another and, in the school context, provides a useful means of enabling usage in one curriculum area to be reinforced in another. A further welcome development in software design has been the liberation from turgid manuals (written by experts for the apparent exclusive use of experts) through the development of on-screen help facilities with improved sophistication, interactive tutorials with diagnostics and 'wizards' providing step-by-step instructions for common tasks.

Lessons from technical innovations

The pathway to the present state of the art in software and hardware has not been without its distractions. The diversity of innovation has often produced a multiplicity and confusion of standards such as those experienced with graphics resolution, disc operating systems, and printers. The pace of innovation has sometimes produced rapid obsolescence, making promised revolutions stillborn. For example, the prospect of storing large programs on portable memory chips was soon superseded by the rapid development of compact hard disc drives. Sometimes innovations have not succeeded because they have underestimated the inertia of the training
cycle for human operators. For example, alternatives to the 'qwerty' keyboard have not flourished so far; it appears that the majority of users, having invested sufficient effort, have learned to live with the conventional keyboard and are unwilling to reinvest learning effort in alternative systems. This example illustrates the role of 'service' or 'operational' skills, as opposed to skills of application, a theme to which we shall return frequently in this book: progress in developing application skill is driven by lowering the threshold of operational skill. The prevalence of rival platforms (proprietary computer systems; PC, Apple Macintosh, Acorn) and the consequent exclusivity of software to particular systems has been an understandable but unwelcome feature of development. However, the more recent development of cross-platform software and the transferability of data between different systems works to everyone's benefit, be they manufacturers, developers or users; greater flexibility encourages more use and is likely to create increased demand.

The aspects of software design that make programs easy to use and understand usually depend upon intrinsic properties such as screen layout, navigation tools and operational methodology. Successive improvements in these have already been mentioned. However, for educational use, there are further aspects which determine the suitability of a program as an educational tool: any consideration of software must also concern the nature and purpose of the activity prompted or served by the program. It is in this respect that the skills of a teacher have a vital role both in design and application. The effective application of software in the classroom requires a range of teachers' skills related to their understanding of the curriculum and their own pupils' needs. The process of software design also demands a knowledge of the learning process, an appreciation of pupils' learning needs and expectations about their responses to the tasks involved. Some of the most successful early examples of science software had their origins in the work of practising teachers; for example, Fiveways Software, Netherhall Software, Science Measurement Toolkit, djb Software and Harmony Software. In contrast, much software published for the commercial and domestic market and not primarily designed for education, often requires adaptation, customization and compromise for educational use. It is inevitable that the design of software reflects its purpose in terms of curriculum fit, pedagogical style and need, so the question of the extent to which designers' imagined purposes and implicit learning model match those identified by teachers is an important issue. Ideally, the development of educational software addresses both pedagogical and technological issues in an iterative process; pedagogy should lead in terms of defining needs, yet be enlightened by technical possibilities; technology should be exploited appropriately, yet be developed in the light of classroom evaluations. The implications of such a thorough model are fairly high development costs which is unfortunate in the light of the size of the education market, being small compared with domestic and commercial markets. Additionally, the accretion of so many user-friendly features in modern program design has added to the sophistication of the development process, demanding the skills of fully professional programmers. Thus the days of the cottage industry approach to software development have well and truly passed. Quality developments in educational software need support at a national level.
Science education and ICT

In certain respects, science teachers have been well placed to take advantage of the ICT revolution. Their practical experience and familiarity with managing, handling and maintaining equipment has enabled many to avoid the technical phobia and amateurism sometimes prevalent in other subject areas. For science also there has been a valuable bonus of opportunities for augmenting practical work in the laboratory. This mode of use has become known as data-logging, a process that involves obtaining physical measurements directly from sensors and storing them in the computer's memory. An important aspect of data-logging is the presentation of the data on the screen, usually directly in the form of graphs. The technical power of a data-logging system lies in the speed and repetition with which measurements can be obtained, displayed and stored. It has been noted previously that the BBC Microcomputer gave a significant boost to this technology in schools by making the "Analogue port", with an internal chip for measuring voltage inputs, a standard feature of the basic model of computer. The connection of a variety of types of electrical sensor to the Analogue port facilitated the measurement of a range of physical quantities such as temperature, light, sound, pressure, etc.

Although the BBC Microcomputer gave unprecedented access to this type of usage, the initial development of the technology tended to be the preserve of the confident enthusiast with a basic knowledge of electronics and elementary programming skill. The practical application of data-logging required the construction of simple, but carefully designed, electric circuits as interfaces between the sensors and the computer. The practical manifestation of these devices usually required the connection of separate power supplies and involved multiple wire connections and 4 mm sockets. This was not a problem for many physics teachers, but it tended to exclude other science teachers who lacked confidence with, or who possessed a phobia for, anything electrical. The emergence of an exclusive club of data-logging practitioners was further reinforced by the need for teachers to also write computer programs to present the measurements on the screen. One of the merits of this situation was that, since teachers understood well the specific needs of pupils' practical work, they accordingly designed programs to fulfil these needs precisely. Such tailor-made programs were often dedicated to the use of a particular sensor or an experiment which made them efficient at exploiting the learning potential. However, without any commonly accepted conventions in software design, some of the results were idiosyncratic and did not necessarily transfer easily from one teacher to another. For the potential of data-logging to develop in a significant way, the technology needed to be simplified and packaged in a form that could be used by a much wider audience of non-technical users. The first serious attempt to achieve this in the UK was the 'Practical Science with Microcomputers' project sponsored by the Microelectronics Education Support Unit (MESU). This developed a simple general purpose interface with a range of sensors, together with a compendium of worksheets suggesting appropriate laboratory experiments using the equipment. Following this, as more manufacturers embraced similar principles, data-logging technology has undergone a succession of enhancements which has broadened its access to a wider range of non-technical users; for example, the elimination of separate power supplies or batteries, the replacement of 4 mm connectors with DIN...
Computer technology and needs

plugs, familiar in domestic audio equipment, the internal calibration of sensors, automatic sensor identification and the automated control of the measuring rate. Also, improved software designs have made a major contribution to broadening the appeal of the technology. As in the earlier pioneering days, the best developments have been guided by pedagogical principles and have avoided the distraction of exotic technical effects. As a result of these developments we can now celebrate a mature technology that requires the minimum of technical skill for successful use.

ICT provision in practice

In the early stages of establishing ICT in schools, progress was driven by a core of devotees whose intrinsic interest in the technology fuelled their perseverance in overcoming the pitfalls which inevitably beset a young technology. Being highly motivated, they would readily tolerate 'unfriendly' software and hardware systems and, indeed, would revel in technical terminology, which became an outward symbol of their expertise. The early growth of 'computer studies' as a curriculum subject was a predictable outcome, conferring identity to the new expertise. For the full potential ICT to develop, however, it was necessary for its application to permeate the whole curriculum rather than a specialized niche; such true integration of ICT would need the participation of the majority of teachers rather than a small group of experts. It would also require the development of a broader educational rationale which embraced the needs of all learners as well as those of potential ICT specialists. Unfortunately, the technical attributes of ICT which fed the professional esteem of computer studies teachers also served as formidable barriers for uninitiated teachers. However, as we have seen from the previous discussion, a succession of hardware and software developments has progressively lowered the operational skill threshold, which has greatly improved access for all. Further improvements in the 'user friendliness' of the technology can be expected, perhaps making it difficult to resist, but there still remain significant barriers to the broader adoption of ICT: teachers' attitudes, resource provision, training, organizational and policy issues all have a bearing on its successful development.

An incentive for innovation is a key factor in helping to overcome barriers. For the technical enthusiast the incentive is implicit, but for the vast majority of teachers with a low intrinsic interest in the technology, incentive is more likely to be driven by a perceived teaching purpose or learning purpose. Experience suggests that teachers are more willing to invest in ICT when they can be persuaded that their teaching might thereby be made more effective or the quality of their pupils' learning improved (Somekh and Davis, 1997, p. 141). This is a complex issue since individual teaching styles and personalities are diverse and, although there will be many overlapping aspects, teachers' perceptions and values are likely to vary in emphasis. By focusing on teachers' 'home territory', the learning process, this book aims to convince teachers that there are many opportunities for enhancing the quality of teaching and learning that should suit a wide range of teaching activity in science.

A clearly evident feature of the present governing culture in education is that incentives are achieved by mandatory instruments rather than by persuasion. In this spirit the National Curriculum sets out expectations for the use of ICT in each subject area and, in its most recent manifestation (DFEE, 1999), there is consider-
able emphasis on ICT as an instrument for enhancing learning. There is no doubt that ICT is taken more seriously when it is incorporated into a scheme of work or becomes an element in an examination syllabus; statements of entitlement and assessment confer value. A science department makes a clear commitment to ICT when it specifies its use in a scheme of work rather than allowing it to exist as a ‘luxury extra’. The recurrent national debate of educational standards, the public scrutiny of the curriculum, the expectations of governors and parents, the accountability of schools through inspection have all contributed incentives to increase ICT provision.

At the national level, policies have had an important influence on the development of ICT. In the past twenty years there have been many valuable initiatives that have developed materials and provided hardware, software and training. These include the Microelectronics Education Programme (MEP) 1980, Micros in Schools Scheme 1982, Technical Vocational Education Initiative (TVEI) 1984, Portables in Schools Project 1990, National Grid for Learning 1998 and New Opportunities Fund training 2000. Sadly, the discontinuity between such initiatives has produced a ‘stop-go’ history of progress, and the frequency with which the name of the principal national advisory organization (MESU, NCET, BECTA) is symbolic of this discontinuity. At a regional level the financial provision for hardware, software and training has been the subject of varying priorities for different local education authorities. Networks for sharing and disseminating good practice have come and gone as the support of teachers’ groups and advisory services has waxed and waned.

By the end of 2000 it is difficult to escape a picture across the country of a patchy allocation and acquisition of ICT resources, although the current bonanza for purchasing might change the situation. However, at the institutional level, even when hardware appears to be adequate, there are still further inhibiting factors which prevent access to computer facilities. A common problem occurs when all the computers are located in a single ‘computer room’, a mode of organisation which serves whole class use well, but which, due to the inevitable booking requirements, does not always serve the curriculum at its time of need. This arrangement may match the needs of computer studies as a subject in its own right, but in other subject areas it encourages the use of ICT as a ‘bolt-on’ activity rather than being integrated into the curriculum. The contrasting situation of computers distributed around the school has the advantage of immediate availability which can serve both planned and serendipitous use, but often only for a limited number of pupils at a time. When computers are thinly spread, the simple expedient of placing them on a trolley can often increase several fold their frequency of use. Thus the chain of processes by which the availability of quality software becomes translated into successful implementation in the classroom has several weak links due to a variety of historical, institutional and organisational factors at local and national level. In view of the commonality of these problems, we encourage our readers to explore the consequent abundance of ideas for solving them that is distributed amongst many schools.

An agenda for innovation

At the present time numerous barriers to the integration of ICT into the curriculum have been lowered: the technical performance of hardware, in terms of processing
speed, memory, display and storage media, and the design of software have served to lower the threshold of operational skill required for use of ICT; the reduced diversity of hardware and software systems, the lowering of cost, the inclusion of ICT in syllabuses and the National Curriculum, the variety of training opportunities all have conspired to present plentiful opportunities for teachers to seize. In order to develop a discussion of the range of ICT applications for science in terms of their teaching and learning value, we propose to consider them according to their curricular purpose. Experience so far has shown that the following purposes for software are relevant to science education:

- providing new knowledge;
- revision of previous knowledge;
- practice at basic skills;
- collating and storing information;
- presenting information;
- exploring, evaluating and applying ideas.

The principles of design and use of science software will be discussed later with examples, but at this stage, in order to begin to understand the 'appropriateness' of the design and use of software, it is helpful to recognize the special 'qualities' of computer technology that have been exploited to serve these purposes:

- calculating power for modelling physical systems;
- graphics for visualising phenomena and for plotting graphs;
- memory for storing large amounts of text and numerical data;
- versatility of handling data; editing, updating, sorting;
- presentational (publishing and multimedia);
- data-logging for scientific measurements;
- storage of pictures, sound and video images;
- communication with remote sources.

A key aspect of the features in this list is the extent to which the computer technology offers an outstanding improvement upon conventional methods. Throughout any discussion of 'appropriate' use it is necessary to evaluate the computer method against conventional methods and consider how they might have superior, inferior or complementary qualities. A further aspect of this discussion is the design strategy adopted for the computer method; there are three main options:

1. the computer method imitates a traditional method or approach;
2. the computer method extends the range of possibilities available in a conventional method;
3. the computer method exploits new ways of working, thinking and learning.

The first strategy is a likely starting point since a teacher's confidence in designing class activities is largely built on previous experience. The second strategy springs from vision of further opportunities arising from the special 'qualities' of the computer technology, as listed above. A pertinent example for science is that of
Teaching Science with ICT

data-logging, which facilitates measurement of a much wider range of phenomena compared with conventional methods. The third strategy is the most exciting because it cannot always be foreseen. New ways of working are only revealed through the experience gained after a commitment has been made to experiment with the technology. For example, superficially a word processor is an electronic typewriter, but in practice it has revolutionized the way in which text is composed, ideas are sorted, redrafted and refined. Now graphics and graphic design are also a common feature of printed text and multimedia technology has developed to offer video and sound as well.

The previous list of 'qualities' focused on the intrinsic properties of software, but the latter examples illustrate important aspects of computer technology that emerge from the process of use itself. Further examples of new processes are:

- computers facilitate individual learning without the full-time supervision of the teacher;
- computers facilitate and encourage collaboration between pupils;
- pupils' errors can be handled in a completely discreet fashion;
- some programs offer prompt feedback to pupils with consequent encouragement;
- more thinking time is available to pupils due to the speed of processing data (searching, sorting, calculating, drawing) and automation of 'gathering' tasks;
- computer-based tasks can be multi-sensory, employing a mixture of visual, aural and kinaesthetic skills.

The character of such new ways of working are sometimes so different that comparison with conventional methods of learning becomes difficult. Herein lies a challenge for the teacher, the challenge of adopting an attitude which is receptive to sometimes unexpected opportunities presented by the new technology. This is just one of a subtle mixture of non-technical, social or institutional aspects which have influenced the pace of ICT innovation in education.

An agenda for training

The motivation of teachers is a key issue to innovation; an inevitable pre-condition of pupils using ICT in the classroom is that teachers themselves be persuaded of the useful purpose of ICT for teaching and learning. It has been noted previously that teachers are more willing to adopt ICT methods and are better motivated to acquire the operational skills for using computers and software if they acquire a vision of its usefulness in educational terms. Discussions of innovation in terms of teaching and learning issues are likely to be fruitful since these are in the 'home territory' for all teachers, whereas discussions with too much emphasis on the technical aspects of ICT might exclude or alienate teachers who lack the specialized knowledge. Thus an important principle of ICT training for teachers is that an educational rationale is high on the agenda.

Revealing a poor level of operational skill in class can be very damaging to teachers' self-esteem, especially for teachers whose classroom persona tends to rely more on their expertise than their inter-personal or management skills. It is sometimes the case that pupils' computer skills appear to be far more developed than their
teachers'. Such skill in pupils is usually of the operational kind; pupils are often very adept at displaying their intricate knowledge of software features. For some teachers this situation poses a threat, whilst for others it provides an opportunity, not only to acquire some of the skills from their pupils, but to make effective use of the resource of pupil skill and help build pupils' own self-esteem. A generally safe strategy for teachers is to concentrate on developing and adapting their considerable pedagogical skills in the context of the new technology. In this respect teachers will always be ahead of their pupils!

Fortunately, one of the most exciting and welcome aspects of the latest UK ICT training initiative for teachers (TTA, 1998) is the dominant emphasis on subject application. A concern for identifying learning objectives in subject defined terms is a recurrent theme in the statements of training needs. Although this represents a welcome shift from 'technology-led' towards 'teaching-led' computer use, for many teachers, the basic learning of operational skill is still likely to dominate their early training needs. We look to skilfully structured training programmes to ensure that teachers make genuine further progress towards the use of the computer as a tool for supporting learning. As an aid to this, the revised science orders for the National Curriculum are helpfully annotated to provide cross-referencing between specific science topics and relevant applications of ICT.

**Summary of themes in this chapter**

During the past 25 years, the physical performance of computers has improved dramatically at ever-reducing cost. A significant effect of improved performance and affordability, accompanied by impressive developments in software design, has been to broaden the audience of users well beyond the original select group of technical experts. In education, the adoption of the technology has progressed as technical obstacles have been removed and an earlier hostile face of software has been superseded with improved 'user-friendliness'. In particular, progress has been facilitated by:

- the reduction in technical knowledge needed for hardware manipulation;
- the reduced dependence on keyboard skill and accuracy;
- the narrowing range of computer 'platforms' used in schools.

Science education has been a fortunate beneficiary of the development of data-logging technology, which supports and enhances practical work involving physical measurements. In the larger curriculum there has been a gradual change of emphasis from ICT as a separate subject to ICT as a tool for learning which has broadened access and encouraged more teachers to participate. Teachers have a vital role in developing purposeful and effective use of ICT in the classroom through their attitudes, skills and vision. The skills they require in using a computer fall into two main groups: operational skills concerned with the use of the actual hardware and software, and application skills concerned with way in which these tools are put into service. It is essential that ICT training for teachers addresses both types of skill. The chief preoccupation of the latter is in methods of designing and organizing pupils' tasks to maximize their learning potential. In conventional class situations teachers
exercise considerable skill in this area; the challenge when using ICT is to re-employ and adapt these skills to new parameters, and to minimize the distraction of operational issues. The approach proposed here attempts to give prime emphasis on the learning objectives of ICT activity and to suggest criteria to enable teachers to assess the appropriateness of software design and make judgements about appropriate use. This involves identifying learning purposes, recognizing the special qualities of the computer technology and matching these together. This will often result in new ways of working.
Chapter 2

ICT for teaching science – some prospects from research

The history of computer use in schools has resulted in a legacy of many new opportunities for science education. Chapter 1 identified several factors that have shaped the contexts in which today's science teachers work and we have seen that the picture is complex. The variation in the levels of resource and in teachers' training needs have begun to be addressed more systematically in recent years through, for example, training initiatives and projects to put computers into schools. Nevertheless, it is probably true that the widespread and routine use of new technology in science teaching remains a goal still to be achieved.

This chapter invites the reader to reflect on some issues that have emerged from practice and research in the educational use of ICT. Some of the issues discussed here can be regarded as having relevance across the curriculum; however, the latter part of the chapter focuses more specifically on themes that have a more explicit science focus. The pace of research in this area reflects that of technological developments in ICT and the chapter is therefore necessarily highly selective. We have not set out to offer the reader a comprehensive account of research evidence in the field. Rather, our ambition is to aid the reader's appreciation of the basis for our discussion of the application of software tools to science teaching, which we describe in Chapters 4 to 9.

The everyday experience of science teachers

New technology and its application in educational settings has developed enormously since its early beginnings but it is telling that many of the issues regarding application of computers in the classroom which faced us in early times are still pertinent today.

Early microcomputers in schools were a focus of interest for teachers and pupils alike. As we became familiar with them, and as the availability and range of software increased (often written by science teachers themselves), computers gradually became more frequently used as additional teaching tools. As discussed in Chapter 1, a number of developments enhanced their ease of use, of particular importance, from a user's perspective was the development of storage media such as floppy discs which provided a more convenient means of transferring software and data between
machines. This development allowed for more widespread sharing and use of information.

Computers were always popular with pupils, even if some teachers were more enthusiastic than others about using them! No doubt many science teachers will have noted, like us, the interest pupils showed in the machines and the positive effects they appeared to have on pupils' ability to intellectually connect with an activity. Pupils typically worked at the computer for sustained periods of time; sometimes this made moving them on to the next activity quite a challenge!

Today, with greater access to computers for teaching in schools, and importantly, their presence in many pupils' homes, some of the novelty effects have probably faded. Despite waves of new technological developments, acquisition of new resources is unlikely to keep pace with these innovations; consequently, science teachers are likely to continue to be faced with using 'old' technology in schools. We should note the potential demotivating effect on pupils of using out-dated technology, nevertheless many science teachers we know still see computer use as an important means of raising pupils' interest and as an additional format of teaching activity. This may be of particular significance in helping to engage underachieving pupils in secondary school science.

Information Technology (IT) has featured prominently in the National Curriculum in England and Wales since its inception and the development of pupils' IT capability was a major part of its rationale. In addition, due recognition was given to the importance of ICT for 'enhancing learning at all levels throughout the school curriculum and in providing opportunities for both independent and collaborative work' (DES, 1989, p. 73). Early thoughts on the use of ICT in schools also included the hope that IT use would 'reflect the use of IT in the "real world"

Computers for science teaching - working with new technology

Chapter 1 described some beneficial attributes of computers that arise chiefly from their calculating power; contemporary experience identifies numerous further benefits. Computers are effective at storing and retrieving large amounts of information rapidly and consistently. They are useful at managing repetitive and complex processes with greater reliability than can be achieved by people. Furthermore, the output of these processes can be displayed in a variety of ways. The impact of these generic properties of ICT on teaching and learning situations has been a subject of interest for educationalists. However, we need to guard against uncritical use of such computing power since the learning purpose might be for pupils to
acquire the very skills that the machine replaces (Scaife and Wellington, 1993). A major theme of this book is that computer-supported science teaching demands critical thinking about its appropriate classroom application.

In considering the benefits to pupils of the labour saving effects of computers, Kemmis et al. (1977) distinguish between what they describe as pupils' authentic labour and their inauthentic labour. Authentic labour is seen as valued learning. On the other hand, inauthentic labour is seen to include 'activities which may be instrumental to valued learning, but are not valued for their own sake' (Kemmis et al., 1977, p. 28). In our discussion, we draw a distinction between skills in ICT use that concern the manipulation of software, and which can be regarded as 'operational', and those skills of 'application' of software for a science learning purpose. There is resonance here with the distinction between inauthentic and authentic labour. This distinction is important in helping us to identify the primary features of an ICT learning activity and those that can be viewed as of secondary importance.

According to Kemmis et al., much curriculum reform seeks to enhance the authenticity of pupils' work by heightening its relevance, making work more engaging and seeking to make difficult ideas more accessible to the pupils. In our view, these ambitions remain relevant in the contemporary context. Moreover, pupils' increasing familiarity and confidence with ICT make computer-supported learning well placed to increase the authenticity of pupils' school experiences as less attention to acquisition of operational skill is required.

A further framework useful in helping us understand the contribution of ICT to learning considers the effects of new technology on users (Salomon et al., 1991). The first set of effects is due to users working with the technology, which leads to an enhanced performance on a task carried out with the aid of technology; Underwood (1994) has described this as using the computer as a 'tyre lever'.

These effects can be considered as an outcome of the intellectual partnership between the user and the machine. This partnership allows the user to shortcut part of the mental effort involved in a task and thereby achieve an improved outcome. The computer, by carrying out some of the lower level operations (for example, repetitive calculation), might liberate the user to perform at higher intellectual levels, which would otherwise be beyond their 'cognitive system' (Salomon et al., 1991, p. 4). It is the reduction in demands on users to process large amounts of information that liberates them to move on to higher-order mental activity. The opportunity for the user to then organize and interrelate ideas ascribes to the user skills akin to the expert rather than the novice. In this way, the performance of the user plus technology can be greater than the performance of the human alone — the 'workhorse' effect.

It is important to note here the extent to which a user can benefit in this way is not an automatic outcome of using computers. Rather, it demands some intellectual effort on the part of the user in interacting with the computer. This effort is, of course, under the user's voluntary control and is not automatic. In science classroom contexts, one can envisage that the teacher has an important role here to motivate pupils and to set targets for pupil activity. The need for users to interact with the technology in a thinking way (what Salomon et al. call 'mindfulness') enables learners to mobilize more of their thinking power and benefit from the economy of effort that the computer brings to the learning situation.
Readers who enjoy computer games will be familiar with features of software that can increase user engagement. Such features include the degree of control that users can exercise, the immediate presentation of results, and the degree of interactivity offered. Additionally, computer tasks present users with intellectual conflict, graded goals and uncertainty. All of these attributes of new technology face the user with choice points that require thought. In our view, well-planned science lessons offer pupils tasks and activities that create a similar experience to arouse and sustain interest.

Readers will appreciate that, even in highly structured situations, not all pupils will expend the intellectual effort required to benefit from engaging with the computer in the mindful way outlined above. The willingness of a user to approach tasks in this way is crucial to developing the benefits ascribed to new technology. This caution serves to emphasize the extent to which the benefits of ICT approaches to classroom activity should be regarded as provisional. The degree to which any potential benefits are achieved in a teaching situation is likely to be shaped by many factors that contribute to the context in which ICT is being used. As we shall argue later, teachers have a key role to play in developing classroom climates that can promote the achievement of benefits of computer use.

A second set of effects of ICT use has been suggested: those effects of technology on the user (Salomon et al., 1991). It is suggested that these are effects that might bring about transferable gains to do with development of skills and abilities. Whether any such skills and abilities are bound by the context in which they are developed, or may be transferable to new contexts, is an important question for us since it raises the issue of science teachers 'engineering' contexts in which transferable thinking skills are fostered. Clearly this has implications for classroom settings employing new technologies, and for developing pupils' skills in making choices about when and how to use ICT in their own activity. Such pupil insights into their own learning strategies are of particular relevance to the current interest in the teaching of thinking skills (McGuinness, 1999); they have also been a dominant feature of constructivist teaching philosophies for many years.

The impact of information technology

After some 25 years of ICT use in education, and after significant research into its effects, there is still some uncertainty over the merits of educational use of ICT. The Stevenson report (1997), which provided part of the backdrop to UK government thinking at the time, still indicated a measure of doubt over the benefits of using computers:

*It seems to us a matter of common sense that the educational process in our country will gain massively as a result of using ICT wisely. If this proposition cannot be entirely proved, it has to be an act of faith. It is important that government makes this act of faith and that we use technology rather than study it over the next decade.* (Stevenson, 1997)

Within the United Kingdom during the early 1990s, two major studies set out to investigate the effects of ICT on pupils' learning. These were the ImpacT study
(Watson, 1993) and the PLAIT report (Gardner et al., 1994). New technologies and their availability in schools have moved on since these studies were conducted (indeed, at the time of writing, a new 'Impact' study is imminent). Nevertheless, the findings of these first major longitudinal studies have been influential in shaping the views of policy makers and researchers in the field.

The Impact study
This study involved over 2000 children of primary and secondary school age in England and Wales. The study identified the contribution to pupils' learning made by ICT, but attention was also drawn to difficulties associated with ICT in use and the implications of this for teaching effectively with technology.

One important finding of these studies was that computers raised pupils' motivation, interest and enjoyment of the subject and raised the status of the subject in their eyes. The pupils' learning was focused by ICT and their attention and activity was sustained over long periods, resulting in raised quality of work. Pupils showed pride in work produced using ICT. Computer-based activities tended to be open-ended, allowing for greater involvement of the pupils. The pupils retained knowledge of their experiences over time and conceptual misunderstandings were made more apparent in computing environments. From the teachers' perspective, many were able to use ICT to support their existing practice. Teachers accepted that computers fostered collaborative work between pupils - an important aspect of classroom practice. Importantly, it was reported that teachers' personal confidence in the value of ICT applications, and their enjoyment in using them, were reflected in pupils' use of the technology.

Problems of ICT in use were also reported in the Impact study. These included technical difficulties with software and management of the ICT facilities but they also included other key aspects of pedagogy. Teachers tended to be constrained by the demands of the national curriculum so that limitations were imposed on what was done with pupils. Teachers became more concerned with outcomes than with process and had difficulty in incorporating ICT-based work into normal coursework assessment. They had difficulty in promoting collaborative work with pupils and tended to use ICT to complement existing strategies. Nonetheless, there were many positive benefits for pupils using ICT: the issues raised by the Impact study have implications for the way ICT is managed in use by teachers to maximize these benefits for pupils. Thus in considering the contribution of ICT to pedagogy and practice: 'the results ... indicate quite clearly that any contribution was dependent upon a range of factors, the most important being that of the role of the teacher' (Watson, 1993, p. 3).

The PLAIT project
The Pupil's Learning and Access to Information Technology (PLAIT) project was funded by the Department for Education for Northern Ireland and carried out by researchers from Queen's University of Belfast. The project placed 235 portable computers in nine schools for one year. Complete class sets of machines were provided in one primary, one special and seven secondary classes. In each of the three target subjects of English, science and mathematics, there were indications of
raised pupil motivation, greater pupil autonomy, enhanced quality of work, and acquisition of transferable skills through the uses of ICT.

The PLAIT project identified several sets of issues having implications for the day-to-day teaching of classes with portable computers, many of which will be familiar to our readers. They are summarized in Box 2.1.

**Box 2.1 Issues identified by the PLAIT study**

<table>
<thead>
<tr>
<th>Technical issues:</th>
<th>Teaching issues:</th>
<th>Equipment issues:</th>
</tr>
</thead>
<tbody>
<tr>
<td>the need to develop teacher competence and confidence in the use of IT tools;</td>
<td>new models of teacher pupil interaction (less teaching from the front);</td>
<td>screen quality on portables;</td>
</tr>
<tr>
<td>implications for teaching schedules in terms of lesson length and planning;</td>
<td>additional teaching effort due to use of computers;</td>
<td>location of equipment in teaching room;</td>
</tr>
<tr>
<td>technical support problems and strategies for minimizing the negative impact of these on lessons;</td>
<td>need for contingency strategies;</td>
<td>software problems (ease of use, guides, virus protection);</td>
</tr>
<tr>
<td>advantages of portable over networked machines.</td>
<td>problems of pupils without machines or forgotten disks;</td>
<td>hardware issues (robustness, durability, portability, power management, support from suppliers, memory, user interface).</td>
</tr>
</tbody>
</table>

It is noteworthy that the majority of the issues listed in Box 2.1 concern operational matters: issues to do with the organization and management of computers in the classroom. An important objective of the PLAIT project was to investigate the contribution of portable computers to the delivery of the curriculum. Within the context of science teaching, a range of ICT applications were studied and some of the benefits of the ICT approach were described. However, in the case of science:

*Teachers reported that the use of portables by pupils had not dramatically altered their own approach to classroom management, nor had it changed their teaching style . . . teachers reported, and the research team's observations confirmed, that they had become more mobile in the classroom and that they interacted more with individual pupils. These extra interactions, however, were mostly about queries or problems with machines. (Gardner et al., 1994, p. 25)*

This statement suggests that at the time of the PLAIT project, there was less apparent concern with aspects of pedagogical content knowledge in relation to ICT. That is the knowledge of how to teach particular 'content' to particular groups of pupils using an ICT approach.
In considering their conclusions to the PLAIT project, the authors comment that:

*The general conclusions are that portable computers in the project resulted (although not universally) in high levels of pupil motivation, harmonious and purposeful learning environments and greatly accelerated information technology literacy among pupils and teachers alike. (Gardner et al., 1994, p. 53)*

Further, they suggest that teachers needed to be properly equipped with portable computers in order for them to fully integrate ICT into their teaching repertoires. Despite various initiatives, including 'computers for teachers' schemes, this remains an unfulfilled ambition in many UK schools.

**ICT and motivation**

Both the ImpacT study and the PLAIT report identified positive contributions to pupils' motivation and learning. The studies also raised questions about the developments needed in teachers' skills and vision for computer use to fully exploit the benefits in classroom settings. Hammond (1994) argues the need for evaluation of effects of ICT on learning to place emphasis on the contextual factors that pertain in its use. Accordingly, consideration needs to be given to 'teachers' and pupils' knowledge and understanding of the software, the characteristics of the software and what actually goes on in the classroom' (p. 259, our emphasis).

This view implies that the positive effects of ICT on learning have as much to do with the nature of the classroom settings in which it is used as with the intrinsic characteristics of the technology itself. It serves to emphasize the importance of the teacher's role as a manager of these interrelated facets of classroom experience when using ICT. Further it serves to remind us of the complexity of classroom use of ICT; it is not as straightforward as some would have us believe.

A detailed discussion of literature on motivation is beyond the scope of this chapter. However, it is pertinent to consider aspects of research into pupils' motivation in computer settings since this has emerged as an important factor in both the PLAIT and ImpacT studies; moreover, much everyday classroom experience suggests that pupils frequently enjoy computer-based activities.

The contribution of ICT to enhancing students' own views of their learning potential has been reported (Cox, 1997). In science, 50% of university students reported never having used ICT at school; of course, this figure is likely to change rapidly over time. However, there was evidence in Cox's study that students' own perceptions of their ability as ICT users motivated them to further ICT use. Moreover, frequency of ICT use appeared to lead to an increase in positive attitude and enhanced commitment to a learning activity. For some students, ICT use increased the importance of a school subject to them. At secondary level Cox reported that 75% of students believed that using ICT made their subjects more interesting. More than half of the school students felt that using ICT helped them to greater achievement. The report indicates a link between enhanced achievement and task engagement. Benefits to students' self-esteem and to their ability to work independently were also reported.

A second study carried out under the auspices of Keele University and the National Council for Educational Technology (Keele / NCET, 1997) during 1995/96
highlighted a number of issues of relevance to teachers. This study indicated that pupils were well informed and enthusiastic about ICT. Important features of ICT-based activities for pupils included autonomy, their heightened self-esteem and the non-judgmental nature of working with computers. The research also indicated that some pupils were de-motivated by poor-quality ICT resources in schools, compared with those available in their homes. Whilst teachers noted that pupils were motivated by ICT use to support teaching, a significant percentage (40%) of pupils claimed only to use computers in ICT lessons, thus supporting Cox’s 1997 findings cited above. The Keele/NCET research identified ‘... potential for much more effective and frequent use of IT to support teaching,’ and noted that ‘There is considerable scope for extending the use of IT as a catalyst for more effective teaching and learning’ (Keele/NCET, 1997, p. ii).

Taken together, these two research reports confirm the motivating effects of ICT in the contemporary context, but they also indicate the need to exploit new technologies further through the development of new teaching approaches. There is also the cautionary note that use of outdated technology can be demotivating. Given the current pace of technological developments and the difficulties faced by schools in matching this pace, it seems that careful attention needs to be given to the ways in which the technology is used to support teaching. This will mean not only attending to the quality of the available resources, but also the range of ICT tasks that pupils are invited to experience, so that unchallenging and repetitive ICT tasks can be replaced with more purposeful ones.

**Learning science and interactions in computer environments**

Over the past thirty years, there has been a great deal of research on pupils' ideas and beliefs about scientific phenomena. This research has explored the ways in which learners develop their understandings of scientific phenomena and has resulted in a so-called constructivist view of learning (Driver and Bell, 1986). These ideas have been very influential in shaping contemporary views of effective teaching and learning in science.

At the heart of the constructivist perspective lies the view that pupils' existing ideas and beliefs are a major influence on the interpretation and understanding given to newly encountered ideas. Other features of the constructivist view of learning are predicated on this central principle. These features – learning as construction of meanings; construction as an active and continuous process; meanings evaluated in relation to pupils' existing ideas; pupils' personal responsibility for engaging in the construction process; and the similarities between understandings constructed by different individuals – have led to the development of constructivist teaching approaches, for example ‘CLIS in the Classroom: Approaches to Teaching’ (CLISP, 1987). The approaches can be generalized as a cycle of activity involving the need for teachers to probe pupils' existing ideas; restructuring of these through activities that challenge existing ideas and lead to development of new ones, which are then evaluated by pupils and applied to new contexts (Driver, 1988).

More recently, Driver *et al.* (1994) developed an account of constructivist views of teaching and learning to reflect subsequent thinking about the nature of scientific knowledge and the role of social processes in the classroom. The account integrates
ideas from personal constructivism, social constructivism and knowledge of the nature of scientific understandings. It highlights the multifaceted nature of the teaching–learning process and the teacher’s role in it. For these authors it is pupils’ engagement and participation in dialogue that is at the heart of science learning.

Interaction needs to figure prominently in learning environments. In science lessons interactions become the essential means through which pupils secure scientific understandings. Although interactions are typically mediated through spoken language, non-verbal exchanges can contribute to mutual understandings when people work together on a task. However, Miller (quoted in Rogoff, 1990, p. 178) has claimed that ‘argumentation’ is the important dialogic exchange that leads to shared thinking, because it can involve resolution of differences leading to new mutual understandings. In our discussion of ICT-based science teaching, we need to recognize that interacting participants can be teachers, other pupils and indeed, the ‘voice’ contributed via computer software.

**Computers as tutors**

We now need to consider some influences of classroom organization of computers. One approach uses the computer as information ‘delivery system’ which can demand responses from a pupil to pre-programmed questions. This type of computer use has been labelled ‘computer-as-tutor’. In this model, the computer acts as the teacher presenting pupils with structured information and questions that invite a response. A frequent criticism of ‘tutorial’ educational software is that its intrinsic design and mode of use in the classroom can constrain the learning experience for pupils (Crook, 1994, p. 13). As Crook points out, developers of educational software have sought to incorporate features that more closely resemble the kinds of interactions which take place between teachers and pupils in ordinary classrooms, and which involve information exchange and evaluative feedback. As technology has developed, more advanced software has emerged which permits greater sophistication in the exchanges between pupils and machines. Such ‘intelligent’ software has arguably reached its current peak of development in so-called Integrated Learning Systems or ILS.

ILS software typically combines information delivery systems with sophisticated management software. The management system enables the monitoring of pupils’ responses to presented information. In turn, the software structures more individualized programmes to meet the pupils’ needs as determined by the management system. From the earliest development of ‘teaching machines’ to the current sophistication of ILS software, the mode of use of these systems is conceived as individual pupils interacting with the machine.

A ‘one computer–one pupil’ arrangement can appear advantageous to the teacher since pupils ‘occupied’ by the machine reduce the demands on teacher time and so liberate more time to devote to others in the class. But this arrangement can lead to separation of the computer activity from the main class activity (Crook, 1994, p. 110). Our discussion above has sought to place high value of the social nature of learning, and in this sense, ‘side-lining’ pupils with the computer away from group interaction could be seen as offering a poorer experience than a non-computer alternative. Of course, this may not necessarily be the case, since the precise task and its mode of curriculum delivery will shape the pupils’ whole experience. Never-
Nevertheless, there is at least a question over the relative value of such 'self-contained' computer experiences.

Organizing computers for group activity

Despite investment, computers generally remain a shared resource in schools. Typically computers are used to support teaching schemes and machines tend to be used by pupils working in small groups. Although group work at computers may be driven by limited computer availability, there is evidence to indicate benefits to pupils from organization of group activity. Johnson et al.'s (1985) study of pupils working on a computer simulation in different group modes, reported that pupils organized in cooperative working groups perform better than groups organized in other ways (as individuals or intra-group competitors). These authors made a strong statement that

\[\ldots\text{ when teachers wish to maximize achievement in computer-assisted learning}\]
\[\text{tasks they will be well advised to structure the lesson co-operatively rather than}\]
\[\text{competitively, or individualistically} \ldots\]
\[\text{The combination of co-operative learning}\]
\[\text{and computer-assisted instruction seems like a productive one for classroom}\]
\[\text{learning. (Johnson et al., 1985, p. 676)}\]

Drawing on this and other work, Underwood and Underwood have suggested that group work at the computer should be organized in cooperative ways. Individual pupils working in such groups appear to take responsibility for their learning, share the learning process and learn more effectively than competitive groups of pupils (Underwood and Underwood, 1990, p. 168). It is important to note however that research into non-computer based group work in primary school settings suggests that mere organization of pupils into groups does not necessarily result in collaborative activity by the pupils (Galton & Williamson, 1992). This finding implies that tasks need to be structured in ways that encourage collaborative activity between pupils working in groups. Again the teacher's role in this management of pupil activity is to the fore.

Science practical work is typically organized as a small-group activity in which pupils share. One can envisage that practical activity can provide contexts in which many of the interactions that offer learning potential can occur. It is important to reiterate that merely organizing pupils into groups for an activity does not of itself ensure the establishment of a productive learning environment. Indeed, it has been suggested that group work can generate too much talk, which may impede pupils' progress (Underwood & Underwood, 1990 p. 160). Some research on computer-based tasks has indicated no apparent gain for a group-based approach over individual pupils working on the task (Light and Colbourn, 1987, quoted in Underwood & Underwood, 1990, p. 161). This research evidence suggests to us that it is the ways in which the teacher prepares for, organizes and manages the pupils' activity during a computer-based task, which are of significance in achieving the best from it.

Computers and talk

The work of the Spoken Language and New Technology (SLANT) project
reported that computer-based activities could be effective prompts for pupil interaction and talk. This work identified the important influence of the ‘acts’ (speech and behaviours) of pupils and teachers in shaping the practical use of software. Mercer describes ‘classroom events’ as being subject to influence by three sets of variables, namely: computer, pupil and teacher variables, which contribute to use of software (Mercer, 1994, p. 27). Although the focus of the SLANT project was on the types of talk occurring between pupils during computer activities, the identification of the influences that shape the context of pupils’ experience of events is of significance here. It is a further signpost to the important contribution that science teachers can make to create productive environments for computer use.

One valuable finding of the SLANT project was that pupils needed to be taught how to use strategies which require them to reason and justify their positions, i.e. they needed to be taught how to talk in ‘exploratory’ ways. Mercer describes ‘exploratory talk’ as being educationally useful because it involves reasoning and argument. These are features which, from a cultural psychology perspective, can contribute to pupils’ co-construction of understandings. In a more detailed analysis of some findings from the SLANT project it has been argued that teachers have an essential role in fostering ‘educationally useful’ talk in pupil groups. The study further indicated that the occurrence of exploratory talk could be increased by engaging pupils in preparatory exercises away from the computer, in which the objective was to familiarize the children with ground rules for talk (Mercer, 1996). Research carried out in Australia studied verbal interactions in groups of ten-year-olds working with word processors or simulation software, and identified ‘cognitively orientated talk’ with similar qualities to exploratory talk (Wild and Braid, 1996, p. 218). The attributes of productive pupil talk described here point to the kind of classroom climate that needs to be encouraged and understood for exploratory talk to be fostered.

In the discussion presented so far, we have raised a number of important issues that will shape our view of effective classroom application of ICT. A recurrent theme is the importance of teachers as organizers and managers of pupils’ learning experiences and whose actions contribute to creating productive classroom learning environments. We have seen that there are benefits from pupils being organized into collaborative working groups where interaction is encouraged, since talk is the predominant medium through which knowledge is constructed. Further, we have seen that talk that involves pupils in argument and in resolution of differences can be viewed as educationally useful; and that computers can be a focus for this talk. We have considered some features of computer (and other) activity that can help to engage pupils intellectually. In particular, we have argued that these aspects of educational computer use are not automatically achieved. In many respects they are contingent on the actions of teachers in designing suitable learning episodes for their pupils.

So far we have considered aspects of the contribution of computers for science learning from a largely generic standpoint. It is necessary for us now to adopt a more science-specific focus.
ICT and group practical work in science

For science teachers, a particular bonus of computer technology is its potential to augment enquiry-based activity. Indeed, as we will see in Part 2 of this book, science learners can benefit from a range of ICT applications, including those that may not have a direct link to traditional laboratory-based ‘bench work’. Nevertheless, it is the direct link between science practical work and ICT that has been a prominent feature of computer use in science teaching. This link is achieved by the use of computers to make measurements that can be stored, presented and explored using software tools such as spreadsheets or tailor-made data logging software. Although the use of such data-logging software is instrumental in the practical setting, it is the science involved in the practical activity that is the intended primary focus of pupils’ attention.

In data-logging activities, pupils need only to make decisions about what parameter to measure, in a suitably designed experiment, and to select the appropriate sensor, to be able to record high-quality data. Quality data is assured because the electronic device removes the high skill demand associated with traditional instruments, and so there is a reduction of error in the data collected. With development of sensors and software, the possibility arose of shifting the emphasis of activity from data collection to more focused consideration of the scientific problem itself (Rogers and Wild, 1994).

Development of data-logging software has meant that experimental data that has been collected electronically can be rapidly displayed on a computer screen, typically as a $y$-$x$ graph. Further refinement has led to the creation of analytical tools, as features of the software, which allow for sophisticated exploration of graphical data (Rogers, 1995; 1997).

In principle, the development of analytical software tools supports an exploratory approach to data analysis and interpretation. In addition to basic operations such as reading point values from graphs, there is the potential for pupils to use software tools more creatively. Consequently there is some scope within the data-logging approach for pupils to devise their own strategies for using software to investigate phenomena. Furthermore, the attributes of the data-logging method offer scope for these software-supported approaches to analysis and interpretation to be deployed in a wide range of science practical settings. New types of investigations of transient or of long-term phenomena become manageable. Thus there is considerable scope for pupils’ enquiry-based work using data-logging technology. This scope derives from two sets of new opportunities; the first concerns the wider range of practical contexts that can be explored with the technology. Secondly, there is considerable potential for pupils to investigate the electronic data they have collected.

In a review of literature concerning the effect on science learning of so-called Microcomputer-Based Labs (MBL), Mary B. Nakhleh (1994) considered the contribution of ICT in three areas: first, the contribution to students’ understanding of graphing; second, the development of science concepts; and third, student’s understanding of scientific experimentation.

Research has indicated that the value of the MBL method derives from four attributes. MBL allows for data to be presented in multiple ways; real-time graphing allows pupils to associate the emerging graph with the physical experimental events;
pupils' effort can be focused on graphical interpretation rather than their construction; and the MBL approach allows pupils to investigate in a scientific manner (Mokros and Tinker, 1987).

In real-time MBL data collection and its on-screen presentation as a graph is almost simultaneous. This has been shown by Brasell (1987) to be most effective in enabling pupils to relate a physical event to a graph, compared both to computer-based approaches where there was a delay between the physical event and its display, and pencil and paper methods. Brasell suggested that the improvement shown was due to the motivating effect of pupils being able to connect the real-time experimental event with the developing graphical image. Moreover, it was suggested that the improvement occurred because the real-time processing of data by the computer reduced the demands on students' long and short-term memory for information processing. In the UK, Phillips (1986) has also suggested that graphical display of data can act as a 'store' of information and so becomes a memory aid for users because there is no need to store raw data in the user's head. So the graph reduces the cognitive demand for information processing.

Linn, Layman and Nachmias identified the memory-support attribute of the MBL environment as significant in research, indicating that MBL helps students to understand and use graphs (reported in Nakhleh, 1994). Nachmias and Linn have also indicated that students using MBL have shown more critical awareness of data, being able to identify causes of unreliable graphs such as scaling errors (see Nakhleh, 1994). Interestingly, Nakhleh (1994) has described the work of Adams and Shrum, which showed no significant difference in students' performance on graphical construction or interpretation between MBL and traditional methods. However, a change was reported in students' attitudes to the MBL approach over time, in that the computer came to be regarded by the students as a tool that freed time for them to do other tasks.

In the UK, Friedler and McFarlane (1997) conducted research into the impact of data-logging on graphing skills in secondary pupils. Using a pre-test and post-intervention test strategy, they found that fourteen-year-old pupils showed gains in graphing skills that were not necessarily replicated in groups of sixteen-year-olds. However, these authors were cautious in their interpretation of findings, particularly since the intervention activities were not the same for the two age groups.

Barton's (1997) comparative study of graphing using computer and non-computer methods has highlighted the flexibility afforded by the computer approach. Real-time plotting has time advantages over manual methods, in particular in encouraging pupils to focus on trends and patterns rather than individual data items. A further important aspect of Barton's study was the potential for engaging pupils in talk about data. The teacher could prompt this discussion, and Barton has suggested that the combination of real-time data display and prompt teacher intervention can be a powerful stimulus for discussion about data. This finding has also been observed in the classroom-based data-logging research reported by Newton (1997).

Kelly and Crawford's (1996) work on discourse in MBL environments in 12th Grade Physics classes has indicated that the computer plays particular roles in these settings. These authors' analysis of students' talk indicated that computer representations are meaningless unless the students bring them into conversation. Thus there is a sense in which the computer contributions play a part in the social interactions in
the laboratory and in the development of scientific understandings. Students invested some authority in the computer contribution. It could be as a source of support to their developing thinking when the students used the machine for example, to support an argument. Alternatively, the computer can become a 'group member' in the sense that it may trigger responses and reactions from students as information is presented.

The computer emerges as a focus for pupils' talk again here: an important feature that can contribute to the learning experience in computer-based laboratory activity. Of particular significance is the social dimension to these group interactions. Here is the potential for computer-based activity to provide contexts that can encourage interaction between groups of pupils. There is the potential for discussion and argument when pupils make or defend a case. These sorts of interaction seem likely to secure pupils' learning about graphical interpretation and the concepts associated with the scientific context in which they are working.

Concerning the acquisition of science concepts, Nakhleh and Krajcik (1993) studied students' understanding of acid, base and pH concepts. They used various technologies (pH meters, computers) and chemical indicators, to investigate the effects on interactions of different levels of information provided by the different technologies. The authors speculated that MBL would engage students in more active thinking because of the high level of information provided by the computer throughout the experiment. The students in the study were asked to provide a commentary of their activity, which the authors then analysed. The main findings of the research indicated that there were more verbalized procedural statements from the MBL groups. The authors considered that this could be because students had to enter data into the computer. There was a decline in the frequency of the IT group's analytical statements but these statements were qualitatively more meaningful than the other non-IT groups. The authors speculated that the MBL-generated graph piqued students' interest and caused them to draw harder on their long-term memories. Students using IT reflected more analytical thought processes, as defined by increased speculation, increased prediction, increased ability to relate these observations to concepts. This increased speculative activity resulted in MBL students producing more acceptable and unacceptable understandings, which the authors suggested had implications for teaching in that there was a need to develop teaching approaches which could address students' unacceptable understandings and shift these towards more acceptable ones.

Nakhleh's (1994) description of research into the influences of MBL on students understanding of scientific inquiry has identified several aspects indicative of support for investigative work. The flexibility of MBL appears to afford opportunities for students to engage in cycles of experimentation, and students' confidence in their own abilities to design experiments, interpret data and draw conclusions. MBL has been seen as an appropriate environment in which to develop scientific reasoning skills. It has further been suggested that MBL does not so much teach students how to think but rather frees them to think about what their experimental data mean. Thus the integration of MBL with other teaching protocols can provide students with opportunities to develop skills in integrating their knowledge and understandings. These findings are supported by those of Rogers and Wild (1996) in the UK, which have indicated the importance of teachers adopting an exploratory
style and investigative approach in order to exploit the new opportunities afforded by data-logging.

It is important for science teachers to understand the need to provide pupils with data-logging activities that can extend computer use beyond data collection to data exploration and interpretation. It is this interpretative activity that can provide opportunities for pupils to develop their skills and scientific understanding by bringing their knowledge to bear on new problems and by applying their ideas (Newton 1998). Such activity can contribute to developing pupils' experience of the higher-order aspects of scientific enquiry.

To summarize the above discussion, research indicates that data-logging has considerable potential to develop pupils' abilities to understand and interpret graphs. This benefit derives from the immediacy of dynamically produced graphs in real time data-logging, which helps pupils link experimental events with the graph 'image'. The reduction in demands on pupils' memory achieved by the computer-presented graph enables pupils to invest greater mental effort and attention to more interpretative activity. Pupils' appear to be more engaged by computer-presented graphs, and they interact with the computer in ways that suggest that they draw on the machine as an information provider and as a tool to answer their questions. The computer can be a powerful stimulus for collaborative group activity, of a kind that seems likely to benefit learning. The combination of a computer-presented graph with appropriate questioning is a powerful stimulus for pupils' talk. The teacher's role extends beyond appropriate intervention to setting tasks in suitable contexts with suitable supporting teaching approaches in order to derive the maximum benefit from the data-logging method.

**Computer use – the implementation gap**

Despite a growing body of research evidence indicating potential benefits for the data-logging approach to practical work, its use in UK schools has grown slowly. Anecdotal evidence of the use of data-logging in schools seems to indicate that its use remains relatively sparse despite improvements in ease of use and sophistication of more recent software. Information from the UK Office for Standards in Education (OFSTED) suggests that IT is generally an under-used resource in secondary schools (OFSTED, 1998; 1999). A dominant theme in contemporary education is that of change. The demands on teachers in the current context are considerable, and there is a range of pressures, which may detract teachers' attention from investing the necessary time and effort in developing computer approaches in science lessons. Nevertheless, it is an ambition of this book that readers will find the arguments and examples presented here to be a stimulus for developing their own use of computer-supported teaching and learning.

**Summary of themes in Chapter 2**

In this account we have considered aspects of the ways in which ICT supports teaching and learning in science. We can distinguish between pupils' inauthentic and authentic activity when working with computers and, for the purposes of our
discussion of software in Part 2 of the book, we have indicated our aim to emphasize application skills over operational skills.

The intellectual partnership between user and computer can lead to enhanced performance on tasks but this is contingent on pupils being thoughtfully engaged with a computer activity. A recurrent theme has been the importance of the teacher’s role in motivating and prompting pupils’ engagement with tasks and in generating a fruitful classroom atmosphere to help secure this end. The intrinsic motivation that many pupils show for using computers in school can help in this process. However, we should not underestimate the difficulties posed to some teachers by practical considerations of ICT resource management in the classroom.

Constructivist teaching philosophies put the learner at the heart of the learning process and opportunities for interactions and exchanges between participants are essential to this. Group work plays an important part in computer-based learning; computers can provide a focus for pupils’ talk and act as a ‘contributor’ to group activity. But teachers need to manage group work so that it is collaborative and productive: a further indication of the importance of the teacher’s role.

The value of computers in pupils’ laboratory work and what research has to say about data-logging technology has been considered at some length. This emphasis reflects the importance of this approach to practical science education and the special contribution it can make to help develop pupils’ ICT capabilities. In particular, we stress the importance of pupil activity being enquiry-based since this approach is well supported by computer software; importantly, it is in accord with a constructivist teaching philosophy which underpins much of our thinking about application of software in science teaching.
Chapter 3

Perspectives on the science curriculum – towards the application of ICT in science teaching

Introduction

This chapter is concerned with the science curriculum in secondary schools. Our purpose is to identify some of the major features of the curriculum and to tease out something of the nature of what and how school pupils are expected to learn in science lessons. We believe that the perspectives we present here will have relevance to science teachers whatever the precise specification of the curriculum; however, much of the discussion is set in the context of the UK National Curriculum for science.

What we intend here is to identify broad themes that will inform our consideration in subsequent chapters of ways of using ICT in science teaching. As we have seen, the development of ICT in science education has reached a point where its benefits for young science learners (and older ones!) are now broadly recognized. In order to understand how these benefits can support and enhance pupils’ experience of learning science, we need to correlate them with the types of knowledge, skills and attitudes that pupils are expected to acquire in the science curriculum.

The purposes of science education

As we look ahead to questions of fitness for purpose of ICT, it is important to give attention to the purposes of the science curriculum itself. The revision process that resulted in the current form of the science National Curriculum in the UK (DfEE/QCA, 1999) provided an opportunity for interest groups to rekindle the debate over the purposes and content of the science curriculum. Readers may be aware that there has been considerable discussion in the science education community about the nature of a curriculum that could deliver education ‘through’ science and one that offers an education ‘in’ science. The following list of purposes is based on those identified in the original non-statutory guidance, which was issued with the first UK National Curriculum Science Order (NCC, 1989). Then, the contribution of science to the curriculum was viewed as
Teaching Science with ICT

- acquiring of science knowledge – understanding of the major concepts of science;
- using scientific methods – applying scientific ideas, skills and strategies in enquiry;
- providing knowledge of science as an intellectual pursuit – understanding how science ‘works’;
- developing science knowledge for active citizenship – to help citizens make informed and responsible judgements;
- providing access to careers in science and technology;
- developing reasoning and thinking skills and fostering certain desirable attitudes.

Readers may wish to reflect on how well the structure and content of the present science curriculum serves these purposes for science education. Our argument here is that they may not all be equally well served in a single curriculum model.

The importance of identifying purpose

Achievement of the overarching aims of science education is dependent on the skill with which they can be broken down into more manageable parts. Clarity of purpose is important at all stages of educational planning, designing curriculum, and defining objectives for lessons or individual activities. Nevertheless, it is useful to keep in mind the broader picture since this provides a rationale for activity and can influence the approach adopted in lessons.

In current UK National Curriculum science, the Programmes of Study set out the knowledge, skills and understanding required in the following four areas of science:

1. scientific enquiry;
2. life processes and living things;
3. materials and their properties;
4. physical processes.

In addition, the Programme of Study sets out the breadth of study through which the subject should be taught. This requirement addresses the contexts, including the use of ICT-based sources and technological applications, in which science should be taught.

The detail of the specification in UK National Curriculum science and the requirements of the attainment targets present, for some people, an assessment-driven curriculum model. However, the importance attached to science in the curriculum is set out in a single paragraph in the Order and this presents some broader aims for science education as follows:

Science stimulates and excites pupils' curiosity about phenomena and events in the world around them. It also satisfies this curiosity with knowledge. Because science links direct practical experience with ideas, it can engage learners at many levels. Scientific method is about developing and evaluating explanations through experimental evidence and modelling. This is a spur to critical and creative thought. Through science, pupils understand how major scientific ideas contribute to technological change – impacting on industry, business and medicine and improving quality of life. Pupils recognize the cultural significance...
of science and trace its worldwide development. They learn to question and discuss science-based issues that may affect their own lives, the direction of society and the future of the world. (DfEE/QCA, 1999 p. 15)

This paragraph contains some useful indicators to the kinds of experiences pupils should enjoy when learning science. Words like stimulate, engage, curiosity, experience, thought, critical, creative etc. indicate to us a mode of working with pupils in science to which ICT can make a powerful contribution. As we discussed in Chapter 2, ICT can sit well with enquiry-based teaching approaches and these can help to engage pupils and deliver the range of experience described above. We will develop these links to ICT more extensively in subsequent chapters of this book, but at this point we must consider some issues that will frame our discussion.

Enquiry and practical activity

The substantive concepts of science (the ‘content’ of the science curriculum) arguably have figured as the most prominent feature of recent UK science curricula. However, the statements on scientific enquiry in the UK National Curriculum, are concerned with teaching pupils about experiment and investigation; these statements are set out in Attainment Target 1 (also known as Science 1 [Sci]). Some principles of enquiry may also be applied to non-practical aspects of learning science, for example in consulting information sources and evaluating evidence. This argument becomes strengthened when opportunities for using ICT are considered, partly because information handling is facilitated by ICT.

There are two main purposes to pupils’ investigative work. First, to encourage pupils to develop their understanding of the substantive science concepts associated with an investigation. Second, there is the opportunity to develop understanding and skills in the processes of scientific investigation. This second knowledge set has been termed ‘procedural understanding’ (Gott and Duggan, 1995). This includes pupils’ understanding of the nature of scientific evidence and of how to go about an investigation. Science teachers need to ensure that their pupils have opportunities to develop their appreciation of experimental and investigative processes through first-hand experience.

We recognize that developing pupils’ skills in scientific enquiry can be challenging but we believe that careful consideration of the design and structure of investigative tasks can make this goal more manageable. During investigative work, the degree of responsibility pupils have depends in part on the openness of the task. Typically, investigative work involves pupils in identifying a problem; deciding what to do and how to do it; allocating roles and responsibilities; carrying out the task; collecting data; analysing and interpreting data; evaluating their investigation and drawing conclusions; and reporting on their findings. The more open-ended the task, the more responsibility pupils will have in each of these aspects of investigations, and the more challenging the activity becomes.

Science teachers need to make judgements about the degree of control ceded to the pupils depending, in part, on the pupils’ experience as young investigators. By ‘closing’ some aspects of a task, teachers can reduce its complexity for pupils. For example, teachers might define the problem for pupils, or provide a method for them
to follow. A second dimension, namely the structure of the variables in the task, also affects task complexity. The number of variables, and whether they are categoric or continuous, contributes to task demand. So there is considerable scope when planning investigations for teachers to select and structure tasks in ways that consider the needs of the pupils and meet their curriculum objectives.

When we reflect on the range of purposes and emphases that can emerge in a practical activity we can appreciate their complexity. Planning practical work, which meets the needs of a wide range of learners and delivers a range of curriculum objectives, is no small task. It requires careful thought and detailed knowledge both of the subject and of the pupils. It requires teachers to put plans into practice in their classrooms in ways that are sensitive to the pupils' needs and which deal receptively with pupil responses. This is highly skilled science teaching indeed!

Practical work - a cautionary note

Despite its common use in the UK, practical work has come under close scrutiny in recent years. In particular, the claims made for it and its value to pupils have been questioned. It is important to consider some aspects of this issue here, not least because the introduction of ICT into teaching provides science teachers with a further tool whose use, we strongly believe, must be considered critically. Research has identified five major categories of teachers' justifications for practical work, which are listed in Box 3.1 (Hodson, 1990).

Box 3.1 Purposes of practical work in science

1. to motivate, by stimulating interest and enjoyment;
2. to teach laboratory skills;
3. to enhance the learning of scientific knowledge;
4. to give insight into scientific method, and develop expertise using it;
5. to develop certain 'scientific attitudes', such as open-mindedness, objectivity and willingness to suspend judgement.

It has been argued that the case for hands-on practical work has been presented so strongly in the past that it has come to be seen as '... the universal panacea, the educational solution to all learning problems' (Hodson, 1990, p. 34). A significant concern is that teachers may tend to use practical tasks as a matter of routine, without necessarily thinking through their purposes or their reasons for choosing a practical activity. Research evidence indicates that, at best, we should be sceptical about claiming too much for practical work. At worst, practical work has been found to counter-productive in respect of some of these claims. The routine use of practical work results not only in teachers failing to recognize the weaknesses of its over use, but also a failure to fully appreciate the skills, qualities and attitudes it can promote (Hodson, 1993).

Hodson makes a strong case for practical work which is more carefully driven by theory so that pupils can notice salient features of an activity and are not so distracted by the 'noise' of less carefully structured practical work. The notion of 'noise' in practical work is worth exploring a little further. If one views such noise as any factor which may distract pupils from the primary purpose of a practical activity, then it is possible to conceive of a number of different forms of 'noise'. For
example, poor quality ('noisy') data can make connecting results to meanings more
difficult; attitudinal noise may arise from the degree of focused attention given to the
task by pupils; or there may be heightened technological distraction, particularly in
a lesson made more complex by the use of ICT. This raises the question of how much
technology is a 'good' thing. Certainly, we argue here that ICT needs to be used
selectively and because it adds value to pupils' experience during an activity. ICT is
definitely not always a good thing, however much pupils may appear to be engaged
by using it!

Computers in practical work – new opportunities

The role of pupils' personal responses to an activity also features prominently in
Hodson's critique of practical work. He argues for pupils self-directing their
investigations in order to gain experience and to build their self-esteem. It is
noteworthy that he identifies computer-assisted learning (CAL) as offering many of
the improvements he argues for. As well as motivating pupils, CAL also offers pupils
the opportunity to work with less 'pedagogic noise' than occurs with ordinary
laboratory work. For Hodson, the concrete experiences of ordinary laboratory work
present pupils with a lot of information, only some of which is useful. For the pupils,
distinguishing between the important and the unimportant presents difficulty and
can inhibit understanding. Computer-aided approaches such as databases and
simulations can reduce this 'noise' precisely because they eliminate the concrete
experience and offer an uncluttered experience. So they can allow pupils to spend
more time on manipulating ideas and building understanding (Hodson, 1992, p. 68).

A broader view of practical work

Any approach that requires pupils to be active participants and that has experiential
qualities can be described as 'practical' work (Hodson, 1992). It is certainly our view
that ICT allows us to apply many of the features of enquiry-based practical work to
a variety of types of information available through software. For example,
spreadsheets and databases allow information to be explored, analysed and
evaluated. Predictions may be made and tested with modelling tools. Information
can be presented on a computer screen in a variety of ways using software tools.
Dedicated graphing software further assists the exploration and presentation of
data. Information in its broader sense, in the form of text, sound and pictures, as
available on multimedia CD-ROMs and through the internet, can be explored and
evaluated in the spirit of investigative science. Whatever the medium, it is pupils' experience of working with it that is important in our discussion and it is to
consideration of features of learning experiences that we now turn.

Designing learning experiences for pupils in science

We saw in Chapter 2 that a struggle with ideas, through talk and argument, is often
the means by which learning is secured. This leads us to the view that in planning
lessons, the design of activities should be shaped by the need for pupils to become
actively engaged with them. By engagement we mean more than pupils being merely
occupied with tasks. What we have in mind is that pupils are encouraged to connect
intellectually with the content of activities. This can be achieved for example by use
of questions, challenges and tasks that prompt pupils to generate a product. Due recognition in this process must be given to the roles that pupils are assigned (or which they might adopt for themselves) during lessons. Computers can provide a powerful means of promoting active engagement and enabling pupils to take greater responsibility for their learning. The impact of computers on traditional views of teachers' and pupils' roles is a theme which will be addressed in Chapter 10.

Within the limits of the science National Curriculum specification, teachers are free to plan and design their own lesson activities. In the UK, the Qualifications and Curriculum Authority (QCA, 2000) has recently published outline schemes of work for the first three years of secondary science education. The status of these schemes is, for the moment, advisory; but they provide teachers with guidance on possible learning experiences for pupils in Key Stage Three, including suggestions for using ICT. In addition, the UK Science Order includes many non-statutory examples of possible ICT uses (DfEE/QCA, 1999). These ‘ICT opportunities’ are flagged as marginal notes in the Order and are intended to offer suggestions as to where ICT can be used to support science teaching; they tend to be rather generic (e.g. ‘pupils could use data-loggers to investigate relationships’) but their inclusion is a step forward from previous versions of the Order.

We acknowledged above the complexity of planning practical activity. The National Curriculum Council (NCC, 1989, p. A11) published a useful checklist for teachers to guide the selection and planning of learning experiences for pupils. This checklist remains useful today and is included here in Box 3.2 as a framework against which readers can judge the qualities of particular teaching episodes.

**Box 3.2 Planning checklist (NCC 1989)**

<table>
<thead>
<tr>
<th>Will the learning experience give pupils opportunity to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• develop scientific strategies and skills;</td>
</tr>
<tr>
<td>• develop attitudes appropriate to working scientifically;</td>
</tr>
<tr>
<td>• develop basic scientific concepts;</td>
</tr>
<tr>
<td>• apply scientific ideas to real-life problems including those which require a design and technological solution;</td>
</tr>
<tr>
<td>• work cooperatively and communicate scientifically to others;</td>
</tr>
<tr>
<td>• develop an understanding of the relationship of scientific ideas to spiritual, ethical and moral dilemma;</td>
</tr>
<tr>
<td>• discuss the ways in which scientists work?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Will the experience:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• stimulate curiosity;</td>
</tr>
<tr>
<td>• relate to the interests and everyday experience of the pupils;</td>
</tr>
<tr>
<td>• appeal to both boys and girls and those of all cultural backgrounds;</td>
</tr>
<tr>
<td>• help pupils to understand the world about them through their own mental and physical interaction with it;</td>
</tr>
<tr>
<td>• involve the use of simple and safe equipment and materials;</td>
</tr>
<tr>
<td>• involve resources and strategies available to teachers;</td>
</tr>
<tr>
<td>• contribute to a broad and balanced science curriculum, bearing in mind experiences already selected?</td>
</tr>
</tbody>
</table>

This checklist puts the pupil at the centre of the learning experience and this is a
standpoint that we strongly support. In the following discussion we consider how teachers’ planning role needs to embrace this perspective.

**Considering roles and responsibilities for teachers and pupils**

Pupils’ experience of the science curriculum is shaped by many factors; chief amongst these will be the tasks and activities pupils are faced with and their prior experience of science. The achievement of learning outcomes is mediated through the behaviours of teachers and pupils. The use of computer-based approaches complements the range of lesson formats available in science teaching, but it also has the potential to change the nature of teachers’ (and pupils’) roles. For example, the ease of access to information afforded by new technologies challenges the traditional role of the teacher as information provider.

The most striking role changes arise because ICT can bring a potential shift in responsibility from the teacher to the pupils. ICT methods have the potential to genuinely support pupils in investigative work because the pupils can be in direct control of software. There is scope for pupils to follow up their own ideas rather than following a ‘recipe’ method offered by the teacher. Moreover, there is potential for pupils to experiment with information in a low-risk way. Thus there is a real sense in which pupils’ independence from the teacher is heightened in ICT activities.

The relative ‘freedom’ afforded to pupils by ICT raises questions about the roles of teachers in these settings. As suggested above, it appears that for pupils to benefit from these new opportunities, teachers need to be seen increasingly as ‘facilitators’ of pupils’ activity. However, this is not to suggest that teachers should leave pupils to their own devices. A subtler shift in the leadership role of science teachers is required so that, through careful preparation, a basis is set out from which pupils can carry out tasks.

As we have seen, appropriate groundwork for pupils’ activity includes raising their interest in problems to be explored and encouraging a questioning approach. The roles of science teachers include, among others, those of enabler, manager, presenter, adviser, observer, challenger, respondent and evaluator (NCC, 1989). In ICT-based activities, much of the teacher’s managerial function is invested in the planning and preparation stages of lessons. ICT activities can place high technical demands on teachers and it is important that science teachers do not become too distracted by the technicalities of managing equipment. The teacher’s roles of enabler, challenger, adviser and respondent can take on more importance and the relative shift in responsibility to pupils that ICT lessons afford does not reduce the importance of these roles.

In highly teacher-directed tasks, the scope for pupils to have first-hand experiences of investigative styles of working is more limited than in the more pupil-centred style advocated here. Where pupils can take greater responsibility, they put their investigative skills into practice and further develop their understanding of scientific enquiry. Teaching strategies and interventions that encourage pupils to mindfully engage in the processes of enquiry and in the consideration of science outcomes, are likely to promote development of these knowledge areas. So, teachers’ planning needs to build in opportunities for pupils to discuss, explain and to justify ideas. Moreover during the course of an activity, teachers need to find opportunities
to focus pupils' attention on procedural features, for example number of measurements, repeats, etc. and relevant outcomes (expected and unexpected) to facilitate pupil discussion. In our view these are essential features of the teacher's role in ICT-based science lessons.

**Active teaching and learning approaches in science**

Pupils' experience of science lessons is influenced both by the format of lesson activity and the style in which the teacher presents it. We place a strong emphasis on pupils becoming active participants rather than passive receivers in their learning of science. It is not too difficult to produce a list of lesson activity formats but the question of activity 'style' is more subtle, nevertheless it is important, and we have discussed this issue in detail elsewhere (Newton and Rogers, 1996). We do not wish to diminish the importance of teacher-centred classroom approaches; we certainly see a place in effective science teaching for teacher exposition and demonstration, and for teacher-led questioning and discussion. However, we believe that these formats of lesson activity can be presented in teaching styles which expect and foster the active participation of pupils. It is a teaching approach that is sensitive to the pupils' learning needs. A key feature of this style of teaching is that it is responsive to the pupils. When working like this, teachers engage with their pupils in a reflexive manner that shapes both the content, direction and tenor of a teaching episode.

The key features of teaching activities and approaches designed in this mode are that they consider pupils':

- intellectual engagement with an activity;
- interaction with teacher;
- interaction with peers;
- response to the task.

There is a wide range of activity formats that can be presented to pupils in addition to traditional 'bench work' and which may help to engage and challenge pupils learning science. The following list of activity types (Box 3.3) seeks to embrace the

**Box 3.3 Science teaching activity types**

- doing;
- thinking;
- active reading;
- active writing for different audiences;
- speaking;
- listening;
- presenting;
- argument;
- making things;
- interpreting for self and others (explaining);
- posing questions;
- making hypotheses;
- predicting outcomes.
spirit of the teaching approach describe above. No doubt our readers will be able to
find some of their own preferred teaching approaches represented in this list. We
would be interested to hear of other examples from science teachers.

In any well-balanced teaching programme we should expect to provide a good
variety of activities, which will stimulate and engage all pupils. But there is an aspect
of balance for which we need to consider the type of engagement or 'learning role'
expected of the pupil when responding to an activity. Underpinning each type of
classroom activity are teachers' implicit assumptions about the pupil's learning role.
Scrimshaw (1997, p. 101) has proposed a general classification of these learning
modes into three categories that can be helpful for describing a pupil's engagement
and in identifying a balance of activities for a teaching programme:

• receiver – pupil is an alert receiver of external knowledge;
• explorer – pupil is an interested explorer of external knowledge;
• creator – pupil is an imaginative creator of ideas and their understanding.

Some activities assume intermediate positions in this classification but this does not
detract from its general usefulness as a basis for describing and evaluating activities.
In particular, the roles of pupils as alert and interested individuals in the learning
process sit well with the importance we have attached to experiential learning in
science. The role of pupils as creators of their understanding is part of the
constructivist view of learning. In constructivist teaching philosophy, pupils need
to be given opportunities, through classroom activities, to build understanding. This
can be achieved for example, through pupils participating in dialogue with their
peers and with teachers. In addition, tasks that generate a product, for example oral
presentations, written reports of investigations and concept maps, are valuable
because the processes of marshalling ideas to create the product can lead to
understanding. As our discussion moves on to consider the pedagogical aspects of
ICT-based activities, the classification of learning roles will help clarify the
contribution of ICT to learning.

Towards teaching and learning purposes for ICT

As readers skim the checklists and activity types lists offered in this chapter, we
might legitimately be asked what additional contribution ICT can make to class­
room experiences. If these teaching ambitions can be achieved through a range of
conventional pupil activity and modes of classroom delivery, why bother with ICT?
It is legitimate to question what the 'pay-back' may be for the financial investment
made by institutions and, perhaps more importantly, for the substantial time
investment required by science teachers to master new technologies and to imple­
ment their use in classrooms. The question must be: what value is added to an
activity by an ICT-based approach?

To begin to answer this question, we need to consider how ICT can be used to
teach science more effectively and we explore this theme, with illustrative examples,
in the following chapters. In setting out our agenda for consideration of teaching
approaches, we suggest that computer software can be used for particular science
teaching purposes. These are presented under the headings that follow. To retain a
focus on learners in this discussion (a position for which we have argued strongly in this chapter) we must consider the links between the teaching purpose for ICT activities and the learners' role.

**Obtaining knowledge**

We saw in Chapter 1 that the facility of computers to archive large quantities of information and to permit its ready retrieval was of potential educational benefit for conveying knowledge. Software that is designed to exploit these properties includes multimedia resources such as CD-ROM and web-based materials accessed through internet 'browsers'. These types of software provide the user with access to information that can be presented in different ways; for example as text, still and animated graphics, and with 'voice-over' commentary, and interactivity in some cases. The feature of rapid presentation of information in different forms serves not only as an engaging information source for pupils but also as a learning aid. This is because of the rapid juxtaposition of information in different forms. Here the teaching purpose will typically involve provision of knowledge and the learners' role is that of receiver. Importantly, the role of receiver need not be as passive as it may first appear. Multiple presentation of information can engage the user as sense is made of the information presented. At another level of sophistication, software designed to encourage interactivity can demand input from pupils and allow more exploratory activity.

**Practice and revision**

The storage and presentation features of ICT have been harnessed by software authors for a second teaching purpose, that of knowledge and skill testing. Arguably at its simplest, this involves presentation of practice questions following or integrated with a software-delivered tutorial. These so-called 'drill and practice' software packages provide opportunities for pupils to revise their knowledge and skills. The learner's role oscillates between that of receiver and explorer as the pupil reviews, revises and reworks previous knowledge. The programs allow a degree of interactivity limited only by their design and scope. The most highly developed form of such software at the time of writing, are Integrated Learning Systems. These systems are able, through the sophistication of their management systems to tailor the presentation of tutorial and test items depending on users' responses. This allows a degree of responsiveness not seen in the majority of drill and practice software and attempts to emulate, albeit in a rather crude way, the teacher–pupil interactions that occur in classrooms. Despite evidence that pupils can learn from ILS software, recent evaluations of these packages have been rather equivocal over their benefits for pupils (Wood, 1998). Of particular significance here are the links made by teachers between the ILS activity and other non-computer learning activities.

**Exploring ideas**

In science, the provision of knowledge through software is chiefly concerned with teaching the substantive concepts of the subject. This is a function of many multimedia learning resources. As described above, the value added by the use of ICT to provide this information arises from the high quality of the materials
presented and from the use of multiple media. However, such software does not typically allow for pupils to contribute their own ideas or support testing and development of these.

Software that lets pupils control parameters and to input data can support more exploratory types of work. Simulation software and, at a higher degree of complexity, modelling software, can demand more of users. For example, the use of spreadsheets to perform calculations on data could demand from the user knowledge of the types of calculation to be performed and of formulae to put into the spreadsheet in order to perform the required operation. Spreadsheets and other types of software that provide graphing facilities enable pupils to explore the presentation of data in different graphical forms, and to look for trends and patterns in data.

In these learning scenarios pupils have opportunities to contribute ideas, test them and develop new understanding. In group-working modes of organization pupils might engage in discussion in order to reach an agreed response to the software. Collaborative pupil activity can place demands on individuals' subject knowledge and understanding, and require application of ideas in new contexts. Thus pupils are encouraged to be imaginative in their responses to software.

Collating and recording
Pupils can use spreadsheets and databases as data collection tools. In the context of practical science, direct links to experiments can be made using data-logging equipment. Here the measurement, recording and presentation of experimental data can be carried out entirely by the computer and associated peripheral hardware. In this type of computer use the learner is a receiver of the information collected by the computer. However, it is possible for data-logging systems to be used in ways that serve other teaching purposes such as the exploration of ideas. Clearly, the mode of use of software must be driven by the learning objectives.

Presenting and reporting
The presentational tools provided by word processing, desktop publishing, web-based and other specialized presentation software offer pupils powerful tools for presenting and sharing their ideas with others. As well as deciding what information they may wish to report, pupils can decide on styles and formats for presenting their ideas. This allows for a degree of creativity and exploration in the search for the most appropriate and effective format. We believe that the creative processes involved in producing reports and presentations help pupils to develop and secure their understanding of science.

We have attempted to identify above distinctive teaching uses for ICT. Importantly the context in which software is used can drive the teaching purpose and the learning roles users adopted. These are summarized in Box 3.4. The uses for ICT discussed above are not tied to particular types of software application; indeed several can serve each purpose. The links between learning modes, teaching purposes and software are illustrated in Figure 3.1. This figure provides an overview of the organization of our discussion of the application of software to science teaching used in Part 2 of this book. The discussion is organized around groups of
<table>
<thead>
<tr>
<th>Learning mode</th>
<th>Teaching purpose</th>
<th>Software tool type</th>
<th>Software instrument</th>
<th>Media</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiver</td>
<td>Obtaining knowledge</td>
<td>Information storage</td>
<td>Database, browser</td>
<td>CD-ROM, web</td>
</tr>
<tr>
<td>Reviser</td>
<td>Practice and revision</td>
<td>Visual aid</td>
<td></td>
<td>CD-ROM, web</td>
</tr>
<tr>
<td>Creator</td>
<td>Exploring ideas</td>
<td>Modelling</td>
<td>Spreadsheet, modelling tools</td>
<td>CD-ROM, web</td>
</tr>
<tr>
<td>Creator</td>
<td>Exploring ideas</td>
<td>Calculating</td>
<td>Spreadsheet, data-logging</td>
<td>CD-ROM, web</td>
</tr>
<tr>
<td>Creator</td>
<td>Exploring ideas</td>
<td>Graphing</td>
<td>Spreadsheet, data-logging</td>
<td>CD-ROM, web</td>
</tr>
<tr>
<td>Creator</td>
<td>Exploring ideas</td>
<td>Measuring</td>
<td>Data-logging</td>
<td>CD-ROM, web</td>
</tr>
<tr>
<td>Creator</td>
<td>Exploring ideas</td>
<td>Publishing</td>
<td>Word processor, desktop publisher, presentation package, hypertext, graphics</td>
<td>CD-ROM, web</td>
</tr>
</tbody>
</table>

*Figure 3.1* An overview of ICT use in science education
Box 3.4 Teaching uses and learner’s roles with ICT

<table>
<thead>
<tr>
<th>Teaching use of ICT</th>
<th>Learner’s role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obtaining knowledge</td>
<td>Receiver</td>
</tr>
<tr>
<td>Practice and revision</td>
<td>Reviser</td>
</tr>
<tr>
<td>Exploring ideas</td>
<td>Explorer</td>
</tr>
<tr>
<td>Collating and recording</td>
<td>Receiver</td>
</tr>
<tr>
<td>Presenting and reporting</td>
<td>Creator</td>
</tr>
</tbody>
</table>

software tools explored through general examples of software instruments and media. We then consider application of the software to science teaching using illustrative case studies.

Summary of themes in Chapter 3

This chapter has considered a number of important themes for teaching science with ICT. We have seen that contemporary science education is concerned with teaching pupils about science and about developing their scientific capability. Associated with this capability in science is a set of attitudes, which together with skills and knowledge, contribute to what it means to be able to ‘do’ science. The science curriculum is concerned with developing pupils’ understanding of science as a body of knowledge and of the ways in which scientific knowledge develops over time. It concerns helping pupils to understand the strengths and weaknesses of science as a way of understanding and explaining the world.

We have indicated that achieving the multiple purposes of science education within a single curriculum model is no easy task. But the ways in which teachers work with pupils and design learning experiences for them are key determinants in developing pupils’ scientific capabilities and in communicating to them about the nature of scientific activity. Activities cast in the mode of enquiry provide a means of raising pupils’ interest and developing their scientific capability.

A major consideration for teachers must be the roles that they adopt for themselves and plan for their pupils to take during lesson activities. Practical work is a common feature of science lessons that provides pupils with opportunities to engage with tasks and to take more responsibility than in some other modes of lesson activity. Practical work can embrace a wider range of tasks and activities than ‘bench work’ and should be used critically by teachers to help secure clear planned learning outcomes for pupils.

There is a considerable range of learning activity types that can make intellectual demands on pupils, and encourage interactions with their peers and teachers. Computer-based teaching approaches are potentially powerful means of creating opportunities where pupils can take more personal responsibility for their learning. However, the decisions that are made by teachers concerning activity types and presentational styles are influential in generating climates for lesson activity where the potential benefits of ICT can be secured.

The range of software types and information storage media currently available can support several different teaching purposes and, depending on the ways in which
Teaching Science with ICT

tasks and activities are designed, can present pupils with opportunities to work in various learning modes. These learning modes can serve different science purposes including raising pupils' awareness of ways of scientific working and the development of constructive attitudes.
**Part 2**

Applying ICT in secondary school science teaching

**Introduction**

The discussion in Part 1 has set out a view of the potential contribution that ICT can make to teaching and learning science. This potential stems from the special qualities of software and how these give rise to purposes which have relevance to science education. In Part 2 we examine in more detail the profound influence that the mode of application of software in science lessons has on the benefits of ICT and suggest teaching approaches which we believe will secure those benefits.

In order to develop the discussion we have classified software in a particular way which links software types to generic science teaching purposes. Each chapter focuses on the use of a different type of software as follows:

- information storage;
- publishing software;
- visual aids;
- calculating, modelling and simulation software;
- graphing software;
- measurement software.

The chapters are presented in a common format to structure and exemplify the argument, thus for each software type we present the following sections of discussion:

1. **Introduction** – to help identify the software type concerned and its teaching usage.
2. **Features of the software** type, which describe their attributes.
3. **Added value**: an analysis and description of the properties of the software and the potential benefit of these properties to learning science. The distinction we draw between properties and benefits is based on the work of Rogers and Wild (1996). This is useful because it distinguishes between those advantages that accrue directly from the self-evident properties of software (for example time-
saving) and those, which are not automatic but depend on the mode of classroom application.

4. **Operational skills**: which set out briefly the technical skills needed to operate the software successfully. We have deliberately avoided too much detail here, since there are other books that provide this kind of information.

5. **Application skills**: this represents our major focus for each type of software discussed. Here we set out what we believe teachers and pupils must do in order to realize the benefits of software set out in our discussion of added value.

6. **Case studies**: these are descriptions of classroom applications with a commentary intended to exemplify the previous general discussion.
Chapter 4

Information systems

In this chapter we discuss the use of information storage and retrieval tools in science education. For convenience we have used the term 'information systems' to include software tools that facilitate the storage and retrieval of information in useful ways. For example, database management software, which exploits the storage capacity of personal computers, provides structured repositories of information that can be interrogated by pupils. The bulk of information is usually in the form of text, but the inclusion of images and sounds is now common, giving rise to the so-called multimedia software. Probably a more significant development has been the growth in the scope and capacity of storage media such as CD-ROM and disk-stores on remote machines, which can be accessed by networking to a local personal computer via the internet. A common feature of these storage resources is that they support interactivity with users.

Taken together, these developments present learners with a vast information store whose richness and diversity is astonishing. The extent of this data source can present teachers and pupils with a valuable resource but it also poses challenges in using it effectively in the classroom.

Recommended teaching usage:

- obtaining knowledge; the learner as a receiver;
- exploring ideas; the learner as an explorer.

Features of information storage software

Databases are software tools in which information is stored in a structured way. The functionality of a database program is determined to a large extent by the organization of its information storage structure and by the facility with which information can be retrieved from the store. In simple databases, information may be stored in matrices analogous to a card index, or in 'hierarchical trees' similar to the structure of folders and sub-folders commonly used in computer filing systems. More complex database structures involve networks of links between items in the database. It is not difficult to appreciate that the complexity of these various organizational structures can lead to differences in their usefulness.
Information in database programs is stored and organized in so-called *Fields*. Fields are information categories and can be of various sizes (*field length*) and different *types* depending on the kind of data stored in it (numbers, words, images, sounds, video clips etc). Usually, databases hold information about a limited range of topics, e.g. chemical elements, planets, and nutritional tables. Thus, within each database the individual *records* will hold the same type of information and so have a common field structure.

The value of a database lies in the ways the information it contains can be manipulated and interrogated. The records stored in a database can be *sorted* in various ways. For example, they could be sorted alphabetically or numerically and in ascending or descending order. The database can be *searched* for particular records; alternatively, all records could be searched for common pieces of information. In more sophisticated databases these *queries* can make use of logical operators (AND, OR, etc.) to generate complex searches. But it is important to appreciate that the usefulness of particular queries depends on the organizational structure of the database.

Ready-made databases useful in science education are available commercially. These provide comprehensive information sources for pupils on particular topics. However, considerable benefit can be gained from pupils making their own databases. Designing and building a database involves pupils deciding what information to collect, how to research it, how it should be structured in a database and how it could be interrogated. Essentially these are problem-solving skills that sit well with certain process skills in scientific enquiry. Science teachers planning for pupils to design their own databases will need to provide activities which offer the pupils experience in the various features of database management systems. This process might start with exploration of an existing database and develop through modifying it using templates, to the designing from scratch of a simple database. There is a similar hierarchy in ‘Task Level’ presented in Chapter 7, where we discuss the use of modelling and simulation software.

*CD-ROMs* are compact disc read-only memory stores. These small discs provide a very convenient means of storing vast quantities of information. Each disc can store the equivalent of a quarter of a million A4 pages of text. It is important to remember that CD-ROM discs are essentially containers of information; they are not themselves software. The huge capacities of CD-ROM discs enable ‘memory-hungry’ file types such as images, sounds and video clips to be stored with ease. This feature has enabled the development of software stored on CD-ROM that incorporates material of different types to produce learning resources that have become known as ‘multimedia resources’.

An important feature of multimedia resources is the structural relationship between the various information sources (and their formats) they offer. Consider how books typically contain text and graphical information organized in a linear way. This format could be adopted in CD-ROM material, but the capacity of CD-ROMs lends itself to complex networks of links between items stored on the disc. With appropriate tools to navigate these items it becomes possible for the non-linearity of the organization of the information to support more complex searching and exploration by the user. Objects and text can be linked together using software features called *hyperlinks*. These hyperlinks appear as underlined text or as image
Information systems

icons and provide a means of moving quickly between the items stored on the CD-ROM. This feature can increase the flexibility of the resource. For the authors of learning material, ‘hot’ hyperlinks provide a way of structuring pathways that learners can take through material as well as allowing users to explore the resource in their own way. This facility is of particular importance in encouraging the user to interact with the material stored on the disc.

Many CD-ROMs designed for use in science education are essentially database management systems but others, as described above, permit more complex links between items stored on the discs. Extensive reviews of CD-ROM titles can be found at the BECTa website [http://www.becta.org.uk/information/cd-roms/] or via the National Grid for Learning website [http://www.ngfl.gov.uk/ngfl/].

The internet provides a huge resource of information for educational purposes. Some of the features of CD-ROMs described earlier can be applied to internet resources. However, CD-ROMs provide self-contained resources whereas the structure of the internet is much more open-ended, allowing access to resources distributed amongst computer servers across the globe. Much of the material available via the internet is relevant to science teaching and it can be much more up-to-date than any textbook. However, there is also a great deal of information which is irrelevant and which can present pupils with ‘blind alleys’ in their research.

In classroom contexts fruitless internet searching can become a great time-waster and be a very frustrating experience. A further problem for teachers arises because the material available on the internet may be inappropriate for the pupils, either in its content or level. Much internet material is undifferentiated and like any such resource, it is therefore unlikely to fully support either the intended teaching purpose or suit the needs of the pupils using it. Well-designed websites, such as those of national science museums, which have an educational purpose, might be expected to offer science teachers and learners more carefully targeted internet material. Nevertheless, we believe that science teachers should be wary of materials offered on a ‘one size fits all’ approach, because similar issues of suitability of content can apply even with the best designed materials. Taken together, these drawbacks mean that successful teaching with internet resources is, in our view, highly dependent on the thinking science teachers do in preparing to use it with their pupils. In this spirit, we need to consider some issues that will need to be thought through by science teachers using internet resources and this theme will be developed when we discuss application skills below.

The National Grid for Learning (NGfL) is an internet-based collection of resources brought together by the UK government to support its drive to raise standards in schools. In addition to the provision of resources and materials to support teaching, learning and administration in education, the NGfL was also set up to provide a means of access to these opportunities and training for teachers and librarians in ICT use.

Launched in 1998, the NGfL has rapidly expanded and essentially provides a gateway to support material and web sites for all education sectors. Parents and school governors as well as pupils, teachers and managers in education are catered for. A particularly useful feature of the NGfL to science teachers is the Virtual Teacher Centre (VTC). Here science teachers can find information relating to:
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- subject resources;
- the curriculum;
- ICT support;
- tests and exams;
- organizations;
- discussion groups.

It is not profitable here to present an extensive discussion of the materials available to science teachers through the NGfL or the VTC. We encourage our readers to examine the resources for themselves according to need and interest. It should be recognized however, that one of the major advantages of making support materials available through these two networks is that they can be readily updated and tailored to the changing needs of professionals much more easily than is possible with paper-based material. In our view, this feature should make them much more useful to science teachers.

One of the potentially most useful features of the VTC is that it provides a 'Meeting Room' facility where professionals can exchange and share information. The use of discussion groups and mailing lists is already extensive in higher education and there are already such discussion groups run in science specialist subject groups and in conjunction with science subject associations. These groups are likely to become an important means of communication between science teachers in the future.

**Added value**

The benefits of database, CD-ROM and internet resources for science teaching flow from their features as information storage and retrieval media, and from those design features that enable a degree of interactivity between the software tool and the user. These are summarized in Table 4.1. As with other software tools, the benefits that arise from these features are secured through careful classroom application and so are largely in the hands of science teachers.

**Operational skills**

We view operational skills as those skills that are required in order to 'drive' the software. The use of these software tools requires familiarity with the generic features of the computer interface, which tend to be consistent for particular computer hardware platforms. These skills involve:

- keyboard, mouse, clicking, scrolling, dragging, highlighting;
- minimize, maximize, undo, redo;
- booting/launching a program;
- managing folders/files;
- open/save;
- file formats;
- editing: cut, copy, paste;
- navigating;
- printing.
**Table 4.1** Properties and potential benefits of information systems

<table>
<thead>
<tr>
<th>Properties of information systems</th>
<th>Potential benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-capacity information storage</td>
<td>• encourages access to detailed content;</td>
</tr>
<tr>
<td>Versatile and speedy search facilities</td>
<td>• provides contexts for applying Scientific Enquiry (Sci) skills;</td>
</tr>
<tr>
<td></td>
<td>• develops search and selection skills;</td>
</tr>
<tr>
<td></td>
<td>• promotes classification skills;</td>
</tr>
<tr>
<td></td>
<td>• enables comparison of information.</td>
</tr>
<tr>
<td>Storage of information in different formats (words, images, sounds, video)</td>
<td>• offers differentiated access to information;</td>
</tr>
<tr>
<td></td>
<td>• presents information in different formats to aid assimilation;</td>
</tr>
<tr>
<td>Hypermedia – provides links between related items and alternative pathways through information</td>
<td>• offers choices and encourages exploration.</td>
</tr>
<tr>
<td>Interactivity – requires thinking responses from users</td>
<td>• encourages collaboration between teachers and pupils;</td>
</tr>
<tr>
<td></td>
<td>• encourages self-questioning and decision-making skills.</td>
</tr>
</tbody>
</table>

Where the information is CD-ROM or internet-based, it is likely that skill in the use of editing features (cut, copy, paste) will be necessary. If information is to be extracted from a source, for example as a database query, the format of the query output may involve the user in having to manage different file types; the 'plain text' format is generally the most satisfactory for transfer between different types of software. Multimedia resources also provide sound and image files that need to be managed more thoughtfully because they require more memory than plain text. Again, familiarity with different file types and the relative economy in memory requirements of some image formats is useful operational knowledge in this context.

**Navigating multimedia resources**

In order to access the information stored in CD-ROM or internet sites, users need to be familiar with the navigation tools provided by the user interface or internet browser software. It is necessary that pupils have skills in systematically navigating and searching the resources in order to avoid time wasting failed searches. Searching may require use of alphabetical, index and contents pages. In the case of CD-ROM materials, there is usually a menu page that incorporates hyperlinks to other parts of the resource. Often the material will be hierarchically organized so that start menus can lead to submenus. In this way the user can quickly find the desired part of the resource. The organizational structure of the material is sometimes presented as a graphic on the start page so that the user is provided with an overview of the whole resource and has a sense of where, in the whole, the desired part is located. The use of menus and 'hotspot' icons allows the user to directly access the required part of the material.
In common with internet browser software, CD-ROMs may incorporate navigation toolbars that allow the use to move back and forward through the 'pages' or screens of the material, or to access 'help' menus by clicking on toolbar buttons with the mouse pointer. In CD-ROM material, the hierarchical organisation of material is sometimes revealed layer by layer as users click on hotspots. Some of the potential benefits to science learners of these graphical features are discussed further in Chapter 6.

Whatever the precise format of the navigation tools provided in a particular resource, the best designed materials will draw on the conventions which have become so commonplace in software driven by windows, icons, menus and pointers (WIMP). These features can add to the intuitive 'feel' of software. Simple web content such as text and pictures can also be readily handled using these tools, but more sophisticated content involving, for example, dynamic images, may require the use of software 'plug-ins' to display it properly.

When considering the operational skills necessary to use a piece of software, clearly pupils need to be taught them and given opportunities to practice. This is of course also true for science teachers! However we wish to encourage our readers to think beyond operational issues towards questions of software application in the science classroom, which is where the benefits of use of can be secured.

**Application skills**

Application skills for software concern the mode of use of the software tool in the science classroom. This requires thought about the software and, more significantly, the contexts in which it will be used. Software tools can be considered as agents through which pupils can access and explore information content. Teachers need to keep the nature of the information content being worked on to the fore in their thinking. Clarity of the science teaching and learning purpose is of primary importance here, since this allows judgements to be made about the usefulness of the content for the desired learning purpose.

Information systems, as discussed in this chapter, fulfil two broad teaching purposes, those of providing knowledge and providing opportunities for pupils to explore ideas. The challenge for science teachers is to design learning activities that will deliver these teaching purposes in ways that encourage thinking responses from pupils. This stance demands consideration of the pupils' role as the learner in the activity. To develop this point a little further, we have seen that information systems can offer pupils access to a great deal of knowledge. The question that has to be addressed is how the pupil can receive this information in a way that promotes learning with understanding. We argued in Chapter 3 that learning with understanding is less readily achieved with the learner as a passive receiver of information. The pupils need to be alert and critical knowledge receivers and this will require us to design activities that arouse their interest and encourage mindful engagement with the material. In using information systems to explore ideas, pupils have at their disposal knowledge bases and software tools that allow them to create their own understanding. Science teachers need to provide contexts in which this creativity can be expressed to serve a science learning purpose.
We now need to think about features of software content that contribute to its usefulness for science teaching. Much of our own thinking in this area has been guided by so-called 'situated approaches' to software evaluation. We believe that, compared with checklists and usability audits, situated evaluations are more useful to teachers because, in addition to describing characteristics of software itself, they prompt consideration of mode of classroom use and of the learners' role. An account of one such approach to software evaluation is the so-called Perspectives Interactions Paradigm described by Squires and McDougall (1996). Whilst a detailed discussion of this approach is beyond the scope of this book, it is important to note that Squires and McDougall set evaluation of the learner focus of software in a constructivist framework. This means that development of pupils' conceptual understanding needs to consider the nature of their existing understanding and how the new knowledge and experiences presented through software can challenge these. An important aspect of this stance is that pupils will engage in an intellectual struggle to embrace new understandings and that this process may require skilful intervention from the teacher in order to facilitate pupils' resolution of this conflict.

In addition to the mode of classroom use, teachers will be concerned to consider the educational value of the knowledge content presented by software. What questions should science teachers ask when evaluating the usefulness of this software information content? We suggest that any evaluation might include consideration of the following issues.

- **Suitability of content** might involve judgements about the aims and purposes of the source and how well these are matched. At a more discriminating level, teachers should consider the selection of relevant information for their science teaching or learning purpose. We reiterate here our concern over 'one size fits all' resources failing to adequately suit the needs of teachers and pupils.

- **Appropriateness of level** of content is important, especially for internet-based material that may be written for adult audiences and so present problems of readability or conceptual demand. This issue leads to questions about differentiation of material that may require reorganization or restructuring to better match it to the ability of the pupils who will be using it. Science teachers might have concerns about the 'tabloid' linguistic style of some websites and whether this might be a threat to developing their pupils' skills in use of language.

- **Reliability, accuracy and objectivity** of information are important considerations, especially when exploring issues-based information sources. Teachers might consider the origins of the information source and whether it offers alternative viewpoints or links to other sources on similar topics, where the reliability of information presented could be checked. The style of presentation of information as fact or opinion and any hint of bias might raise concerns about the objectivity of the source.

- **Availability and currency** of internet sites is an issue because they are subject to change and relocation (or even disappearance!). A major advantage of the internet as an information source is that it can be very up to date. Well-designed sites always include a date line that enables users to know when the information was written. The same considerations of currency should be applied to other information sources such as CD-ROM material and databases.
The issues addressed above are chiefly focused on the authenticity of software-based information sources. There are additional application factors that science teachers will wish to address however, concerning how pupils will use these resources and what their relationship is to off-computer activity.

- **Focused enquiry** is necessary to avoid time wasting and fruitless searches. This means that careful thought needs to be given to the purpose of any information search *before* pupils use the computer. Some teachers we know use paper based search forms on which pupils must work out the purpose and even the early stages of their search strategy (keywords for example) before they are given online access to the internet. There is clear sense in this strategy in terms of cost savings in time and access charges. Moreover, it is a useful training discipline for pupils to work out the preliminary stages of their search and to have this vetted by the teacher. In this way, pupils develop good search habits and the teacher retains an important measure of control and can monitor the suitability of the pupils’ activity (not least in terms of risk assessment). There is the added benefit of allowing greater pupil access to the on-line facility, since no one group or individual need monopolize the resource.

- **Intranets** can provide pupils with access to web content stored on a local network server. The content can be tailor-made, written by the science teacher for a specific class and purpose. Alternatively it might consist of a series of pages downloaded from the internet and stored (with due regard to copyright) on the local server using web content capturing software, the pages can then be browsed off-line by pupils so avoiding live access charges. A major advantage of local intranet is that it provides a safe, self-contained and limited information resource. The material placed on an intranet can be document files produced in a word processor, spreadsheet or database files, downloaded web pages viewable in a browser or CD-ROM material delivered from a locally networked CD-ROM server. The authenticity of the content and its suitability can be assured because it will have been previewed and selected for its purpose by the teacher. This selection process also limits the scope of the content to something more easily managed by the pupils and enables a much easier risk assessment of its content to be carried out by the teacher. Since pupils do not have direct access to the internet, they are working within a ‘walled garden’ of information sources provided by the teacher.

- **Remodelling information.** Whatever the information source being explored by pupils it is necessary for the teacher to consider how the pupils will make use of the information. We discuss some aspects of this issue in greater depth in the chapter on publishing tools. But to reiterate the point here, it is important that when accessing information for a science purpose, pupils are required to do something with it to avoid just copying or printing it out. We believe that a useful approach is for the teacher to think about how the pupils might transform the information in ways that challenge them to think about its content. Remodelling information provides a means by which pupils can engage intellectually with content as well as consider alternative formats for presentation.
Case Study 4.1: Using a database to explore human variation

Learning objective:
• to understand continuous and discontinuous variation.

Added value:
• searching and sorting;
• rapid graphing;
• exploring relationships.

This example illustrates how pupils can use a database in order to explore patterns of variation in humans. The activity helps to develop the pupils' understanding of the influence of heredity and the environment on causes of variation. It involves data collection, input into a database and the use of the database tools to investigate patterns in the data set.

In any activity that involves the design of a database it is necessary to give preliminary thought to the questions to be answered since this will determine the kind of data to be collected. In this example, the teacher uses a pre-designed database that accepts data on the following pupil characteristics:

- name;
- arm span;
- hair colour;
- tongue rolling ability;
- shoulder span;
- sex;
- height;
- shoe size;
- eye colour;
- body weight;
- hand span.

Pupils collect their personal data in a small group activity and record it on a data collection sheet, which specifies the units for measurements. The sheets ensure that all the collected data is in a similar format (pupils could, of course, be involved in designing the data collection sheet). The data then needs to be entered into the database programme. We can view these processes as essential preparation for the next phase of activity where pupils begin to work on the data using the tools in the database software.

First, the data can be presented in different ways using graphing tools, so pupils can explore the usefulness of pie charts, bar charts, histograms and scatter graphs for displaying data sets.

Then the data might be searched to find the names of all those in the class who can roll their tongues or who have red hair. This search can be extended to find those pupils who can roll their tongues AND have red hair. We can then ask if there is a similar pattern of tongue rolling ability in people with black hair.

This data set allows questions to be asked about patterns in individual data sets, which can be explored using sort tools, e.g. sorting in height order to find the tallest or shortest and the person of middle height. Other questions help pupils to appreciate different types of variation, e.g. tongue rolling ability, arm span, height and sex.

In addition, pupils can explore relationships between data sets, e.g. is there a link
between height and weight or shoe size and hand span? This question could be answered by drawing \( y-x \) graphs of paired data sets.

In these examples, the value added by the computer is in the speed with which these queries can be answered and in the use of graphics to display results. The data collection process in this example can be fun, but the speed of the calculation and display offered by the computer allows much more useful work to be done by the pupils on the data set and helps to keep science questions to the fore.

Case Study 4.2: Exploring the Solar System via the internet

Learning objectives:
- to understand the relative positions and sizes of the planets;
- to research physical properties of planets.

Added value:
- rapid searching of information;
- animated graphics and video clips;
- links to relevant material;
- interactivity.

In this example, pupils use the internet to gather information about the planets and their discovery. This develops pupils' understanding of the relative positions and sizes of the planets, and the relationship between the surface temperature on the planets and distance from the sun. The example illustrates how the internet can be an engaging and interactive information source.

Pupils are provided with a data collection sheet on the planets. The sheet requires pupils to find information for each planet's diameter, mass, distance from the sun, surface temperature, day length, orbital period, etc. In addition, pupils are asked to research the discovery of the planets and to note some of its properties. Some teachers might choose to provide partially complete data collection tables in order to reduce on-line time.

The pupils then access an internet site providing information on the planets, for example the BBC Planets site (<http://www.bbc.co.uk/planets/> (Fig. 4.1)). Subject to copyright considerations, teachers might decide to download information to a school intranet. Pupils can then search the website for information and use the collected data to answer questions that explore relationships between certain properties. For example, pupils might explore the link between distance from the sun and surface temperature, or the link between mass of the planet and gravitational force. Teachers might decide to explore these links by asking pupils to export data into spreadsheets for graphing.

At face value, the use of the internet as a data source for this activity may appear to have limited advantages over pupils consulting textbooks. However, websites offer a potentially richer and more engaging environment for the pupils to research. Colour graphics may be mixed with still photographs and video clips that enable pupils to 'see' some of the features of the planets. By using hyperlinks, information can be structured in manageable amounts for pupils. For example, information on the moons of Jupiter can be 'nested' separately from statistical information on the
planet. Pupils can open different parts of the website simultaneously using information 'frames'; this can aid comparison of information. Furthermore, structuring information like this can aid research because the amount of detail facing pupils can be limited. These features exploit the interactivity which is possible in an electronic medium and offer pupils control over the way they use the resource.

**Case Study 4.3: Using a CD-ROM to explore cells and cell functions**

*Learning objective:*
- to understand structure and function in plant and animal cells.

*Added value:*
- audio, text and photographs;
- animated graphics and video clips;
- overlay of information;
- interactive tasks;
- multiple pathways.
This example describes how a CD-ROM resource (Fig. 4.2) can be used to develop pupils' understanding of the structure of cells and the functions of some organelles.

![Image from the CD-ROM 'Cell City' (© 2001, Anglia Multimedia Ltd)](image)

A menu screen, which provides users with an overview of the contents, drives the CD-ROM and access to different parts is achieved by clicking on icons with the mouse pointer. Pupils can visit various parts of the CD-ROM to find out about microscopes and what can be seen with them; or where cells are found and how big they are. They can choose how to navigate the resource.

Pupils can select magnified views of cells, which present photomicrographs at different magnifications. They zoom to a cell 'tour' which gives an overview of structure and uses 'hot spots' to provide labels for the cell components. The CD-ROM has modules of information and activities on different cell components. The CD-ROM uses the metaphor of a walled city to help develop pupils' understanding of cell compartments, functions of organelles and the idea of these being integrated in a living cell. Pupils are invited to view video clips of a city and images of cell organelles where comparisons are made between the functions of a town hall and the cell nucleus, or power stations and mitochondria for example. Explanatory text overlays graphics to develop vocabulary and provide information. Pupils are offered puzzles that reinforce understanding; these make use of graphics and sound to reward responses and pupils earn points for correct answers. The puzzles provide fun tasks, but more challenging questions are posed when pupils complete a module. A glossary and help facility allows users to get support when they need it.
The CD-ROM exploits the full range of media; it mixes photographs, video, sounds and graphics to provide information and make connections between ideas. Together, these provide a stimulating 'environment' to develop the metaphor of the cell as a walled city. The structure of the resource encourages exploration which can be done in different sequences. Compared with a conventional paper-based resource, the multimedia package offers multiple images which can be explored interactively.
Chapter 5

Publishing tools

An important purpose of science education is to help pupils to communicate their ideas and report their discoveries. Learning to communicate science requires knowledge of concepts and experience of the language styles and conventions used in science. Teaching about scientific communication makes an important contribution to pupils' understanding of what it means to be scientific. As part of this endeavour, writing has an important role and the process of writing helps pupils to work out their ideas and learn science. With the present range of software applications for publishing information, the opportunities for variety in forms, purposes and methods of writing have expanded considerably.

Although writing in school science may not typically be considered as 'publication', much of what pupils write in science has a public audience of teachers, parents, other pupils and school inspectors. In opening their writing to others, pupils make public statements of their scientific knowledge and understanding as well as of their skills in the use of language.

For the purpose of our discussion, we consider a range of software that can be used to support pupils in presenting their work. This includes word processing, desktop publishing, web authoring packages and software for public presentations. There are, of course, differences in the functions of these types of publishing software, however, from the perspective of learning science, these tools have many common attributes.

Recommended teaching usage:

• presenting and reporting; the learner as an explorer, the learner as a creator.

Features of publishing software

Word processing and desktop publication applications usually result in printed paper copy. Other software that specializes in electronic presentation generates an image, which can be projected onto a screen. This type of software now includes facilities to incorporate sound, images and movies, in addition to textual effects, to
Publishing tools

provide sophisticated presentations on computer screens or as projected images for larger audiences.

Increasing ease of access to the internet has coincided with development of specifically designed software for generating and publishing personal ‘web pages’ of information. This type of software application enables the user to produce a variety of screen layouts with structurally complex mixes of text, backgrounds and graphics without the need for mastery of the codes and procedures that the program uses to generate them. Whilst each of these publishing technologies has unique features, there is considerable overlap between them and this will provide the core of our discussion in this chapter.

**Word processing and desktop publication** software are powerful tools for presenting written and graphical information. Word processors allow pupils to create and edit documents that contain both text and images. A wide choice is available for the appearance and layout of text (font styles, sizes, emboldening, italics, underlining, justification, multiple columns, tables, etc.). These facilities make it easy to achieve a professional appearance in the finished piece. Documents can be stored and transferred electronically and, of course, they can be printed on paper to produce so-called ‘hard copy’.

Desktop publishing (DTP) software can support the integration of different text styles, fonts and images in more varied ways than is possible using word processors. DTP software can also be used to generate materials with a wide range of layouts. Science students are commonly asked to produce posters to express their ideas or to summarize topics; the features of DTP software are well suited to such tasks. The combination of presentational formats available with DTP allows pupils to express their ideas creatively. This flexibility is often achieved at some cost to ease of use because of the limitations of DTP in manipulating and editing text compared with simple word processors. However, the word processing packages frequently associated with ‘office’ software usually incorporate many of the features of DTP. Such sophisticated word processors often include tools that permit the user to explore different layouts and styles as well as incorporating images; consequently, they provide a powerful means for presentation of pupils’ work. For the teacher, it is important to match the choice between use of word processor or DTP with the writing task.

**Web page authoring** software offers a similar range of features but a particularly useful feature lies in its ability to link together objects and pages using so called ‘hyperlinks’. These links, which appear as underlined text or as graphical icons, allow pupils to switch between pages from a variety of sources with a greater degree of flexibility than is possible with linearly organized text. The navigational coding used by hyperlinks is incorporated into files saved in the ‘HTML’ format. Any such file may be viewed using a ‘web browser’ program.

The hyperlink facility has appeared as a feature in some word processing software, which allows documents to be saved in the HTML format. Although they may be considered as useful ‘entry level’ tools for producing web pages, such word processors are relatively unsophisticated and lack some of the functionality of dedicated web authoring software. Despite this shortcoming, the major advantage of word processors as web authoring tools rests in their familiarity for many users. With knowledge of how to produce documents with word processors, it takes only a click of a mouse button to convert a document into an internet-publishable format.
**Electronic presentation** software allows the production of sequences of 'slides' incorporating text, images, sounds, animated graphics and text effects to produce sophisticated electronic presentations. Some of these features are dependent upon the material being presented to an audience using a data projector or 'beamer' connected to the computer. But the same type of software can be used to produce slides for use with overhead projectors or indeed 35 mm transparencies. A further advantage is that it is easy to produce handouts and notes from the outline presentation.

On a cautionary note, there is a real danger that over use of special effects simply detracts from the message in the presentation. It is important that the inclusion of effects or animated graphics in an electronic presentation should enhance it. Just because it is possible to achieve a certain effect does not make it desirable! The great strength of this type of software is that it streamlines the collection and organization of themes and ideas for a presentation. Not only can the software generate a good quality product for presentation, it can also be easily modified and adapted to suit particular purposes.

**Added value**

It is useful to draw a distinction between attributes of software and the potential benefits for teachers and learners, which can arise from its use. Table 5.1 summarizes some properties and potential benefits of publishing software.

<table>
<thead>
<tr>
<th>Properties of publishing tools</th>
<th>Potential benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ease of clarity of presentation</td>
<td>• encourages writers of all abilities: reduced threat for weaker writers than with pen and paper;</td>
</tr>
<tr>
<td>Clarity of presentation</td>
<td>• improves self-esteem;</td>
</tr>
<tr>
<td>Easy modification of text using editing tools</td>
<td>• encourages attention to content rather than presentation.</td>
</tr>
<tr>
<td>Proofing tools for checking spelling and grammar</td>
<td>• pupils develop thoughts in their own way;</td>
</tr>
<tr>
<td>On-screen presentation of virtual pages</td>
<td>• ease of change encourages reflection and refinement;</td>
</tr>
<tr>
<td>Incorporation of graphics and images</td>
<td>• remodelling text encourages thought.</td>
</tr>
<tr>
<td>Templates providing frames for structuring text</td>
<td>• knowledge of spelling and syntax improved.</td>
</tr>
<tr>
<td>Hyperlinks make links between items</td>
<td>• encourages dialogue between teachers and pupils;</td>
</tr>
</tbody>
</table>

Table 5.1 Properties and potential benefits of publishing tools
The value of the writing process

The writing process can be viewed as comprising of two phases: the composition phase, in which ideas are generated, and the more mechanical transcription phase, where the text is drafted and formatted into its presentation form. The most obvious advantages of publication software relate to the transcription phase; the ease of editing text and arranging layouts contribute to the production of high-quality presentation, almost regardless of the skill of the user. But the question remains of the benefits of these features to learners in science. On further reflection we realize that the provisional nature of what is placed on the computer screen can also contribute to the composition phase; publishing tools are useful for drafting or ‘collecting’ ideas in lists or as keywords, which can be subsequently developed as the piece is redrafted and revised. An important aspect of recording and communicating ideas through text, graphics and speech is their relationship to supporting and clarifying pupils’ thought. Publishing software can support the generation of ideas and can be an aid to organizing them to be communicated to others.

The editing capability of software permits a more dynamic approach to the creative writing process than that demanded by pen and paper. Text or images placed on the computer screen do not have the permanence of those committed to paper. The provisional quality of the on-screen product provides users with a low-risk setting in which to explore ideas and presentation formats. This feature is of value in building pupils’ confidence in working with the medium.

The flexibility of formatting that the software affords enables users to express their creative flair. However, being faced with a wide range of possible text formats and layout templates can lead to over-emphasis on the appearance of the final written product at the expense of its content. The facility to change surface features of text formats and styles so readily can distract users into playing with the appearance of the text to the detriment of putting mental effort into the deeper (and more difficult) creative processes of composition. There are questions here for science teachers who need to consider how an activity can be managed so that appropriate effort is put into the creative process.

As we have seen elsewhere in this book, the computer screen can become a focus for group activity and discussion in the classroom. The screen presents a public display of pupils’ work from WP or DTP software and this ‘publication’ of work, even at the early stages of generating ideas or drafting, can encourage collaborative activity in which pupils and teachers can participate.

It is necessary (and a requirement of the UK National Curriculum) for pupils to be taught to express themselves correctly and appropriately. This means that in their science education it is important that pupils use correct spelling, punctuation and grammar, and that they learn to write coherently.

Operational skills

These skills are concerned with the knowledge of the features of publishing software and of their use in generating a product. With the increasing sophistication of this software category it would be easy to produce a lengthy list of the extensive range of such features. Readers need only explore the toolbar buttons in their favourite
It is more useful here to view operational skills genetically. This skill-set thus includes:

1. keyboard and typing skills;
2. editing: cut, copy, paste;
3. file management: open, save and print;
4. using proofing tools: spelling checker, grammar checker, dictionary and thesaurus;
5. using font selection and formatting, styles;
6. inserting tables and charts, drawing lines and shapes;
7. using layout and tabs for positioning text and graphics on pages;
8. using templates;
9. importing text and graphics from other sources, e.g. CD-ROM, clip art;
10. adding hyperlinks.

At face value some of these tools are concerned solely with the presentational appearance of text and images on the screen. However, they also have potential benefits in supporting the writing process and so merit closer scrutiny in the context of their application in science teaching.

Application skills

We now wish to consider in more detail the value of publishing software for supporting the development of pupils' scientific understanding and their ability to communicate about it. As in other chapters where we discuss application skills, our focus must be on the teaching purpose and the learning roles supported by the software. For publishing software, the main teaching purpose is for pupils to present and report their work to an audience. We will argue that producing a 'publishable' product can involve pupils in exploring external knowledge and in expressing their creativity by manipulating ideas. The discussion is based on our view that the processes involved in these activities can help to build pupils' scientific understanding.

Word processors as thought processors. A major benefit of the editing features of word processors is the ease with which ideas can be collected on the computer screen and subsequently sorted into a useful order. This allows for more divergent thinking than is possible with linear text. Of course, 'brainstorming' ideas in this way is perfectly possible with pen and paper but the editing tools of word processors allow ideas to be manipulated in an exploratory way to look for useful groupings or sequences.

Science provides a range of contexts in which pupils can develop their skills in reading and writing. Pupils need to be able to produce logically structured and coherent writing, with due regard to correct spelling, punctuation and grammar. They need to be aware of the specific vocabulary and language patterns used to communicate science, and to have a sense of audience for their writing. In developing these abilities, pupils need to be provided with opportunities to
experience communicating in different forms and contexts, including more creative forms, which at first sight may seem alien to the typical style of scientific writing practised in schools. We believe that publishing software is a powerful resource for promoting this development, but the skills of employing software effectively relate to broad issues associated with writing in general:

1. identifying writing purpose;
2. identifying audience;
3. selecting a suitable genre;
4. structuring text;
5. remodelling text (redrafting).

As with using other types of ICT in science, it is important to be explicit about our learning purposes. If we are to realize those benefits that derive from the software properties themselves, we need to consider how these features can be applied in the science classroom.

In science, a significant proportion (perhaps most) of children's writing is concerned with reporting on practical work, making notes and responding to questions. Each of these is, of course, a valid activity in its own right. However, we wish to encourage additional writing forms that can add variety to pupils' experience of learning science. This can sometimes present science teachers with a problem, but consideration of the application skills listed above can provide a starting point for developing pupils' active writing and helping them to find a 'voice' in their written work.

What are we writing for?
All writing should have a purpose and this needs to be understood by the pupil being asked to write. In science, pupils use writing to record descriptive accounts of observations they may make. They produce written accounts of practical procedures and instructions that inform the reader of what was done; such accounts typically report findings and include explanatory accounts in which other scientific ideas are used to make sense of findings.

There are other writing purposes that could find a place in science lessons, for example, arguing a case, writing newspaper reports, and keeping a learning log. Creative writing can also be used in science and this can include pupils writing poetry on scientific themes or producing imaginative prose, for example, descriptive accounts of 'journeys' through the human digestive or circulatory systems. Often these writing tasks capture pupils' imagination and provide a stimulating context in which they can explore their scientific understanding.

Who are we writing for?
Knowledge of writing purpose leads to questions of audience: for whom are we writing? Consideration of this issue raises questions of style and of formality in the writer's chosen voice. It can lead to consideration of the extent to which use is made of specialist language and to which explanations are provided. Pupils writing accounts for each other are likely to choose a different style than if they were writing display material for a parents' meeting for example. Other examples include
representing information for younger pupils, or writing a report to present in a debate. It can be a useful exercise to give pupils a topic and ask them to explore communicating about it to several different target audiences. In this kind of exercise pupils need to work on the scientific ideas to explore and experiment with the selection of suitable content and the language registers to be used.

What form should the writing take?
This is an important question that can lead to a greater diversity in pupils' science writing. Pupils are often encouraged to write things 'in your own words' rather than copying, but this is no easy task. It assumes that pupils have a good understanding of the content to be communicated and the necessary skill to restructure the information in a suitable form. Asking pupils to reword something they read in a science textbook (which has itself been drafted and redrafted by the author and the publisher's editorial staff before it gets into print) can be close to asking the impossible!

One solution to this problem is to provide supporting strategies to pupils that can help both to shape the form of the writing, and develop understanding of its content. The improved understanding comes from pupils working on transforming the content into a different form (Lewis et al., 1995).

Writing frames are useful devices to help pupils organize their written work. Expository writing frames provide structure and 'starters' to which pupils can respond. For example, science teachers typically provide headings (aim, apparatus, method, results, etc.) to structure pupils' reports on experiments. This idea can be taken an important stage further by providing prompts that probe pupils' knowledge and orientate their thinking about what they write.

Working on scientific ideas in text
The ease with which text can be gathered, cut and pasted using word processors offers a powerful tool for creativity but it also raises the risk of pupils plagiarizing information sources. Although many pupils know that copying is inappropriate, when working with specialized text, they often lack the scientific understanding or language skills to be able to find alternative written forms for information (Lewis et al., 1995). We have suggested that consideration of writing purpose, audience and form can help to develop pupils' understanding of written communication and stimulate thought about its content. As well as reinforcing our aims to use writing to stimulate thought as set out above, directed activities related to text (DARTS) can be used to reduce opportunities for plagiarism.

DARTS offer science teachers a wide repertoire of text-based activities that can stimulate and challenge pupils. The primary purpose of DARTS is to engage pupils in a thinking way with the messages in the text. These tasks are easily produced using a word processor and they can be completed on-screen by pupils. Such activities can be graded in difficulty by their design and on-screen completion can exploit the editing features of software.

Text completion is one of the most straightforward types of DART activity. This involves tasks of the 'cloze' type where gaps in a paragraph of text must be filled. By careful deletion of words, teachers can prepare text that will make pupils think. Such
tasks can be differentiated by provision of 'word banks' or clues for some pupils. The use of drop-down lists in word processors can provide pupils with a menu from which to select the appropriate word.

Disordered text presented in an electronic form can also provide a useful stimulus to thought and group discussion. Pupils can use the cut and paste editing tools to reorder text correctly and print out a final copy. Such tasks lend themselves to sequenced events, for example experimental procedures, historical discoveries and pathways.

Pictorial forms have featured in science education for a long time. The use of a schematic diagram to explain the stages of an experimental procedure has proved to be a useful memory aid to pupils. Graphics packages and the drawing tools in publishing software provide resources that can be used to generate such schematics. For pupils they can provide a bridge to the written text, pupils can interpret diagrams and produce written accounts of procedures, for example. As an alternative the pictorial version can be annotated or overlaid with a verbal commentary using presentation software.

Text remodelling involves pupils in converting text from one format to another; for example, pupils can be given prose from which information can be extracted to a table or vice versa. Such an activity involves the pupils in thinking about the content and meaning of the text in order to be able to organize it appropriately in its new format. There are a large number of possible formats that lend themselves to this type of active writing. These include charts, hierarchical tree diagrams, flow charts and Venn diagrams, all of which may offer teachers insights into their pupils' understandings of the content knowledge displayed in the diagram. Of course, given the features and flexibility of software, pupils can also develop their own ways of displaying information.

Text remodelling can include writing in different genres. Asking pupils to change the format of prose to that of news articles, letters, diaries, faxes, journal reports, etc., provides a wide range of creative writing opportunities where they need to engage in a thinking way with the content of the text. It exploits the features of publishing software in a way that pupils can find engaging. Moreover, it serves the dual purpose of developing pupils' understanding both of science content and styles of communication.

Highlighting text using coloured markers (or their on-screen equivalent in word processors) is a further technique for focusing pupils' attention on text. Pupils could be asked to read a text and to highlight all the terms concerned with a particular scientific theme, e.g. uses of plastics, types of fuel, examples of solids, liquids and gases, herbivores and carnivores and properties of substances connected with molecular movement. In these examples, the pupil is required to make selections of items to highlight and these will not simply be random choices – selection for a purpose demands thought and promotes discussion as choices are justified.

Whatever the medium used for pupils' communicative writing, a key focus for teachers must be to design learning activities that demand pupils engage with and think about the science content of the material. Whilst learning to use a publishing tool can contribute to pupils' ICT capability, we need to retain a focus on its application in scientific contexts.
Teaching Science with ICT

Integrating material using ICT

As teachers make greater use of publishing tools for teaching science, so the flexibility of software can promote a more integrated experience for pupils. The use of standard file formats means that it is relatively easy to exchange and share files between different software applications. Import and export of files between packages is a useful operational skill and this enables links to be made between materials in different formats. For example, image files used in electronic presentations can be imported into word processors or exported in a format readable in a web browser; data files collated in a spreadsheet can similarly be imported for electronic presentation or use in a pupil worksheet.

More innovative applications of word processors include their use to produce 'electronic worksheet' materials for presentation on a computer screen rather than for production of hard copy. These can incorporate hyperlinks to related pages of information to produce a resource that can be interrogated flexibly. This type of use enables a degree of interactivity between user and resource that exploits features of software, which is not possible with paper copy. For example, it is possible to combine, in a single worksheet, an editable text box, which might contain a text completion task for pupils, with information in the form of non-editable text or graphics.

Finally, exchanges between software applications become very straightforward with integrated 'office' software packages, and this offers the teacher a broader repertoire of teaching resources including animated graphics and video clips. It can also support very creative teaching approaches based on file sharing. Pupils can work with the same material in an electronic worksheet that the teacher might use in an electronic presentation to the whole class. This has the advantage of conveniently offering pupils a more harmonious experience of whole class teaching and individual group work, than would be otherwise possible.

Case Study 5.1: Supporting pupils' writing about practical investigations

Learning objectives:
- to develop pupils’ understanding of writing about science investigations;
- to evaluate procedures and experimental evidence.

Added value:
- provides a memory aid;
- prompts thinking;
- collation, organization and editing ideas.

In this case study, pupils use an electronic worksheet to help them write a report on a practical investigation. The worksheet provides a type of writing frame that helps to structure the pupils’ written account of the investigation.

The worksheet exists as a template in a word processor. The template contains a list of 'sentence starters' whose purpose is to structure the pupils’ writing and to act as prompts to their thought.

Examples of the some of the sentence starters include the following statements:
What I thought would happen was... 
I thought this because...
I noticed that...
The pattern in the graph was...
The graph tells me that...
The results mean that...
I know this because...
The results agree with my prediction because...
The results disagree with my prediction because...
The reliability of my results is...
One thing I didn't expect was...
I was surprised by...
A problem I had was...
What I need to do is...
It would be a good idea to...
I could improve my experiment by...
I could investigate my new ideas by...

Teachers can design differentiated versions of the template in order to meet the needs of pupils of different abilities. For example, some pupils will use the basic template and editing tools to collect ideas under groups of statements they have selected for themselves. They can then cut and paste these into an account of their investigation being edited in another file.

At another level of use, teachers might decide to provide only a limited selection of starters in order to steer pupils' activity in a particular direction, e.g. towards interpretation skills or evaluation of procedures.

Some pupils may need more help than is provided in the sentence starter, here teachers could include under each statement examples of the kinds of things they expect the pupils to write about. For example:

What I thought would happen was...
Here you need to make a prediction to say what you thought the results would be.
I thought this because...
Now you need to try to explain why you thought you would get the results you predicted.

It is not difficult to amend templates like this to provide pupils with further support in the form of examples of what they could write under each starter, which will model the kind of language they need to use.

Case Study 5.2: An interactive worksheet on the Carbon Cycle

Learning objectives:
• to understand the processes in the carbon cycle.
added value:

• links images with text;
• prompts thinking;
• improves task authenticity.

In this case study, pupils study how the carbon cycle helps to maintain the composition of the atmosphere. The pupils are provided with an interactive worksheet (Fig. 5.1), the purpose of which is to help pupils link the parts of the carbon cycle together in the correct sequence. The worksheet is presented as a template in a word processor.

The interactive worksheet includes a diagrammatic representation of the carbon cycle using simple graphics. Each graphic has an empty text box associated with it, which the pupils are required to fill with an explanatory statement selected from a bank of statements provided at the bottom of the worksheet. In addition, the various parts of the carbon cycle graphics are linked with 'process' arrows to indicate the

Figure 5.1 Interactive worksheet featuring the Carbon Cycle
relationships between the parts. Each process arrow has a text box associated with it that the pupils need to label to identify the processes of combustion, respiration, photosynthesis and fossilization. Again, these are provided for the pupils in the statement bank.

In this part of the activity, the pupils essentially have to be able to match the explanatory statement or process label with the appropriate part of the diagram. They do this by selecting the text using either the cut and paste editing tools or ‘drag and drop’ feature of the word processor.

In a second activity, pupils are provided with a paragraph of text that explains the features of the carbon cycle. The text contains some ‘scrambled’ words; these are words in which the letters have been deliberately jumbled. In some word processors, the words will appear underlined as they are misspelled. The pupils are required to unscramble the jumbled words using the drag and drop facility to produce a paragraph of sensible and correctly spelled text. Having completed the two tasks, pupils then print out paper copy for their personal notes.

In both these task examples, pupils are required to consider the content of the text and to use their scientific knowledge and understanding to produce a correct response to the worksheet. The activities have their non-ICT equivalent in paper-based cut and glue tasks, but the ICT approach significantly reduces the time spent on the mechanics of cut and paste and focuses attention on the science in the task. The linking of processes and explanations with graphics, and the thought required to unscramble text engages the pupils in working on the scientific concepts in the topic.

Further thoughts on teaching science with publishing software

The discussion in this chapter has sought to identify the features of publishing software that can help pupils to communicate their scientific understanding. It is through the processes of preparation for communication that the benefits for science learning can be secured. These benefits arise through pupils selecting and organizing information, reinterpreting it for different audiences and remodelling its form. The point of using publishing software in science must be that the software helps the pupil to process text and graphics in a way that engages the mind and links with the concepts and ideas that are the subject of the activity. It is important for us to bear this in mind when planning teaching activities for pupils using publishing tools.
Chapter 6

Visual aids

Graphics features in software have proliferated enormously in recent years, greatly enhancing the visual appeal of screen layouts in a wide range of applications. More importantly, most modern software makes extensive use of visual cues to organize information on the screen; frames, buttons, symbols and images all help the user to understand procedures and locate functions quickly. Also, photography has substantially transferred to the electronic media, allowing users to store and reproduce high-quality still and moving images. Together with similar facilities for the digital recording and reproduction of sound, these technologies have contributed substantially to the birth and development of 'multimedia' software.

Recommended teaching usage:

- obtaining knowledge; the learner as a receiver;
- exploring ideas; the learner as an explorer;
- presenting and reporting; the learner as a creator.

Visual features of software

The graphical user interface (GUI), pioneered on Macintosh computers and exemplified by MS Windows, is now a standard feature of computers in domestic, commercial and educational use; we now take for granted the pointing, clicking and dragging techniques with the computer mouse which have made modern programs swift and efficient to use. This development has been facilitated by the remarkably improved technical specifications of present-day computers compared with those of previous generations in respect of their high-resolution monitor screens, large volumes of electronic memory and very fast processing circuits.

The use of graphics carries a heavy demand on computer memory capacity for the storage and manipulation of images. To improve efficiency, several techniques have evolved to minimize the demands on disk space and processor speed. In principle there are two main methods of presenting images on the screen: bitmaps and vectored drawing. A bitmap is produced when all the pixels in a rectangular area of the screen are individually set to a particular colour and brightness. This is a
'memory-hungry' method but it is well suited to managing images such as photographs, which contain a large amount of detail. It is also good for presenting video clips, which require the rapid replacement of bitmaps, each representing a frame of the movie. The vectored drawing method involves drawing lines and geometrical shapes very rapidly on the screen. This method is better suited to simple graphic images and animated graphics, which do not contain too much visual detail; the information for such images is stored as a series of instructions which can be stored more compactly than bitmaps. For both methods, techniques have been developed to compress the stored code in formats such as TIFF, JPEG and MPEG, etc. (A similar approach to the storage of sounds also exists: WAV files contain a detailed definition of the shape of sound waves whereas the more compact MIDI files contain a series of instructions which generate pre-defined sounds through the sound circuit board in the computer.)

For our purposes here, it is not profitable to describe in excessive detail the attributes of computer-based visual aids since they are present in such a wide diversity of software. Instead we will focus on issues which influence their role in aiding pupils' understanding and creativity. In the first instance, the visual conventions implicit in the design of 'Windows' software facilitate the transfer of operational skills from one software program to another. For example, the widespread use of 'cut, copy and paste' symbols allows these functions to be instantly recognized, whatever the type of information involved; screen 'buttons' are readily identified by their 3D appearance and a visual depression effect. Secondly the use of graphics features such as icons, frames, colour variation, different font styles and sizes are widely used in instructional software and information systems to discriminate different categories of information, highlight salient features and generally indicate the structure within information presented on a screen. Thirdly, many types of software incorporate drawing facilities for creating diagrams which are readily incorporated into documents or screen presentations. These provide the electronic equivalent of drawing a diagram in an exercise book, but with the great advantage that, once created, a diagram may be stored, retrieved, edited and used many times over. Collections of graphics files and libraries of 'clip art' are widely available on disk and the web; assuming that pupils can find what they need from such collections, images are easily blended with text using word processors, presentation software and web authoring software. Finally, the technology that enables pupils to originate their own photographic and movie images is readily available in the form of video cameras and digital cameras. Either may be connected to the computer to download the image information for storage on the hard disk and subsequent inclusion into documents and presentations. Directly connected video cameras, 'webcams', are often promoted for on-line picture transmission in the manner of a vision telephone, but they are also very useful in science for recording video sequences of experiments involving motion; once captured, the images can be analysed frame-by-frame with suitable software to generate distance–time and velocity–time graphs.

**Added value**

In this section we consider how the visual features of software provide potential benefits to pupils' learning. The main points are summarized in Table 6.1.
Table 6.1 Visual properties of software and potential benefits

<table>
<thead>
<tr>
<th>Visual properties of software</th>
<th>Potential learning benefits</th>
</tr>
</thead>
</table>
| Use of symbols and icons, reducing reading demand | • time bonus; speeds up performance of tasks;  
• easy transfer of operational skills between software. |
| Use of colour, varied fonts and text sizes as visual cues, emphasizing the structure of information | • aids to comprehension and directing attention. |
| Use of hotspots and tabs to give access to further information | • detail can be hidden until required;  
• reduces information overload;  
• retains an overview. |
| Overlaying of images | • assists the interpretation of information;  
• associations between images; e.g. symbols may be linked with photographs;  
• showing patterns;  
• enables comparisons between images. |
| Animation | • assists visualization of difficult concepts. |
| Digital photos and video | • obtain new insights from image analysis;  
• can investigate a wide range of off-site phenomena;  
• perform experiments on motion; obtain graphs. |

The general use of symbols and icons in software aids the recognition of program features and leads to an economy of learning effort. This particularly applies to the range of operational skills needed to use programs and part of the success of the 'Windows' user interface derives from the way in which skills acquired from one program conveniently transfer to many others. This is a small contribution to the general need to minimize the learning effort devoted to technical operational issues so that greater emphasis can be given to purposeful uses of the software.

Good communication, whether it be with text or pictures, requires attention to several aspects of presentation. For example, it is important to structure information in units of manageable size; with text, this entails avoiding the use of long sentences and paragraphs containing too many ideas which might lead to difficulties in understanding; with pictures, excessive visual detail can be confusing and distracting from the principal features. Further, in the case of text, it is useful to provide evaluative cues as aids to understanding; this might involve highlighting particular words, identifying different categories of ideas or revealing links between them. Both aspects of presentation are well served on the computer screen by the varied use of colour, font style, font size and visual devices such as frames and bullets. Many programs use these visual techniques to help structure information, making it more easily understood. 'Hotspots' (areas on the screen which become active when the mouse points to them or clicks on them) are useful devices for reducing the amount
of information visible at any one time but still permitting ready access to more detailed information on demand. Thus a screen layout can present a simple clear message, but much more detailed information can be made to appear when hotspots are activated.

Imagery and visual effects in software inherit a variety of techniques previously developed in conventional photography, film loops and video cassettes. A very useful effect consists of overlaying a photographic image with diagrams, pointers and explanatory text to assist their interpretation. For example, symbols may be linked with photographs to show patterns, emphasize certain features or demonstrate associations between images. Animated images and video clips are useful for demonstrating changes and for visualizing difficult concepts such as those involved in three-dimensional structures. Such effects acquire special benefits in the software environment since images can be handled with great versatility, often with a high degree of user control. As with many ICT applications, the choice and control available to the user provides an interactive experience unrivalled by conventional methods.

When pupils wish to incorporate original photographs into word processed documents or software presentations it is necessary to obtain the photographs in a digitized form. This is very straightforward with digital cameras which, when connected to the computer via the 'serial port', can send digitized code directly to the program running on the computer. Using this technology, the whole process of taking photographs and presenting the results on the screen can be much quicker than with conventional film, which requires developing and printing. Once in a digital form, a photograph can be scaled or edited to suit a variety of publishing purposes. Similar opportunities exist for the capture, storage and manipulation of movie images using a standard video camera (connected to the computer via a digitizing circuit) or a miniature telecommunication video camera (webcam). Of special interest to science education is the possibility of recording the motion of vehicles, people or objects in laboratory or everyday situations for subsequent analysis using software. Distance, velocity and acceleration data can be obtained using a frame-by-frame analysis technique similar to the methods of stroboscopic photography, but with the added advantage that graphs can also be obtained promptly. The software technique can be applied to a wide variety of motion phenomena beyond the scope of normal laboratory resources, especially through collections of video sequences available commercially and offering scenarios ranging, for example, from a game of tennis to impact testing on motor cars.

Operational skills

The skills required for viewing and manipulating images are fairly straightforward, drawing on the standard range of mouse-based skills: pointing and clicking, drag and drop operations, identifying ‘hotspots’, using play/pause/stop controls. Similarly, for creating images using drawing packages, the required skills involve the fairly standard range of tools which have developed for defining lines, shapes, colours, thickness, grouped objects, etc. For using proprietary or previously prepared image files, pupils need to know how to import or export the files. Knowledge of image file formats and how to select a suitable format is also useful.
Application skills

Although software explicitly exploiting visual features is diverse, our discussion of their application will focus on three main types of learning activity:

- obtaining knowledge; the learner as a receiver;
- exploring ideas; the learner as an explorer;
- presenting and reporting; the learner as a creator.

The first two types of activity are implicit in much multimedia informational software, tutorial and revision software. Most examples are designed for use by individual pupils or small groups and are well suited to independent or home study. There is a clear parallel with the use of beautifully illustrated textbooks which can be beguiling to pupils but which also often need a clearly defined purpose. For the teacher, this involves several important initial considerations: to evaluate the learning potential of the resource, identify suitable learning objectives, design the task and then give appropriate guidance. With software there is the potential bonus of an interactive experience, but genuine interactivity must ensure a thinking component and the task design must overtly encourage this aspect. As we have discussed previously, software with a high visual content can offer many alternatives and present many choices, all of which demand ‘mindful engagement’ to secure usefulness towards learning. An ever-present danger is for activity to succumb to arbitrary ‘clickiness’ with the computer mouse, by which pupils wander along random pathways through the material on offer.

These principles do not necessarily require every activity to be highly specified and tightly constrained. Ideally, pupils have well formed habits of asking questions which give direction to their explorations. Teachers are familiar with the need to strike a balance between giving direction and allowing freedom, between instruction and exploration, between authority and devolved responsibility. Unstructured activity and serendipity can be motivating, but unlicensed freedom can be unproductive. Our plea here is that these teacher skills are brought to bear on task design and that suitable support materials such as worksheets or on-screen prompts reinforce the chosen purposes. Throughout, activities are designed to foster a questioning approach. Pupils should view visual material with intent, be prompted to look for certain features, make comparisons, think about links, identify the patterns or structure in information implied by visual cues, go back and look at images again, and so on. With the ever-present challenge of coping with the bombardment of information, it is worthwhile to train pupils to spot visual cues which can sometimes help them to distinguish main themes from detailed embellishments, and to evaluate information generally.

Pupils can be encouraged to incorporate visual cues in their own presentation and reporting activities. Modern word processors and presentational software provide numerous opportunities to vary font style, size and colour of text. Together with the inclusion of graphics, photographs and video, pupils have often acquired these skills through the school’s ICT skills curriculum so that the application of these methods in science lessons should provide useful reinforcement of that curriculum. For some pupils, without a mastery of the operation skills required with drawing packages, the
use of such tools is inappropriate. A convenient alternative is to use ready-prepared
clip art, but if a lot of time is spent in searching for a suitable image, the time saving
is lost. Again the principle of balance arises; it is possible that pupils' enthusiasm for
employing drawing and publishing tools becomes a time-consuming distraction
from the more important scientific thinking. When this is the case, traditional
handwritten reports might represent a much more time-efficient method! Here is yet
another choice demanding teacher judgement.

Finally, the use of video cameras for recording observations of moving objects
gives scope for the application of motion theory to a wide variety of phenomena,
both inside and outside the science laboratory. The chief emphasis in the activity
should lie in the analysis of the captured video to plot distance–time graphs. Many
of the skills discussed in the chapter on graphing software are applicable here.
Several proprietary packages offer a good range of pre-recorded sample movies
which are useful for practising these skills before pupils apply them to their own
movies.

Case Study 6.1: Learning about the electric motor

Learning objective:
• to understand the forces which cause rotation in an electric motor.

Added value:
• use of colour as visual cues;
• use of hotspots to control display;
• overlaying of images;
• animation.

In this example a tutorial program explains how the force on a wire carrying a
current in a magnetic field is applied to the design of a simple motor. The sequence of
screens illustrates:

• a current passing through a straight wire producing a magnetic field;
• how the field is investigated with plotting compasses or iron filings;
• the use of the right-hand grip rule to predict the direction of the field;
• the overlapping fields produced when a current carrying wire is placed in the field
  of a magnet;
• the direction of the force experienced by the wire;
• how a motor coil, made from wire, carries a current conveyed through brushes;
• how the current reverses twice per revolution of the coil;
• how the cyclic reversal of the current causes the similar reversal of the forces
  acting on the coil needed to maintain circular motion.

The illustrations perform an explanatory task which, in a traditional textbook,
normally requires multiple diagrams and text explanations. Here, the screen
sequence exploits the interactive opportunities for superimposing images to assist
comparisons, hiding explanatory text until needed, animating images to visualize
three-dimensional effects and using video clips to assist explanations of experimental
procedures. Hotspots are used extensively to superimpose explanatory arrows and lines on the photographs to show the directions of the compass needles, the patterns of magnetic field lines, the directions of currents and forces. Other hotspots are used to reveal explanatory text and superimpose labels on the diagrams. Diagrams and photographs are mixed to show connections between them. Further hotspots generate audio explanations when they are clicked. The overall effect is to present uncluttered screens with clear images and diagrams but facilitating the superposition of further diagrammatic detail or explanatory text when required (Fig. 6.1).

**Figure 6.1a** Image from the CD-ROM ‘Electricity and Magnetism’ (© 2001 Anglia Multimedia Ltd)

**Figure 6.1b** Image from the CD-Rom ‘Electricity and Magnetism’ (© 2001 Anglia Multimedia Ltd)
In use, pupils progress through an essentially linear sequence of screens but with several optional side branches. The sequence includes some 'visual cloze' test items involving drag and drop operations, for example, locating direction arrows and labels on diagrams. The test items are useful in that they require pause for thought and arrest the temptation of pupils to race through the screens superficially. It is always a good feature in software when pupils are also free to navigate back to previous screens to revise or check what they learned earlier. For some pupils it may be useful to augment the test items with further questions on a supplementary worksheet in order to draw their attention to certain features which might be overlooked in haste. This idea could also be used as an accompaniment to a second viewing of the program to make it more productive than mere repetition. However, it would probably be a mistake to build excessive writing activity around a program which essentially derives its value from its visual qualities.

<table>
<thead>
<tr>
<th>Sample questions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• What is special about the shape of the magnets used in the model electric motor?</td>
</tr>
<tr>
<td>• Why does the rotating coil of the motor experience both upward and downward forces?</td>
</tr>
<tr>
<td>• What causes the direction of the current in the coil to change as it rotates?</td>
</tr>
<tr>
<td>• How could you make the coil rotate in the opposite direction?</td>
</tr>
</tbody>
</table>

**Case Study 6.2: Animation demonstrating change of state**

*Learning objectives:*  
• to interpret changes of state in terms of the particulate theory of matter.

*Added value:*  
• animation;  
• visualisation of a theoretical model.

This is an example of an animated diagram using computer graphics. The basic idea has been presented for many years in films, film loops and videos, but in this computer version the user has a much greater degree of control over the display. The main part of the screen display is shown in Figure 6.2.

The sequence of animations covers the usual changes of state:

• a solid subliming;  
• a solid melting;  
• a liquid evaporating;  
• a liquid boiling;  
• a gas condensing.

The pictures attempt to imitate real experiments which can be conducted in the laboratory, which makes them a useful accessory for explaining changes of state.
observed in lessons. The animations can be switched to 'theory' mode by clicking on a button which makes the particles visible. Each animation emphasizes the connection between the motion of the particles and temperature of the substance. In each case the pupil can control the starting temperature by adjusting an icon. Changes of temperature are shown simultaneously on a temperature–time graph. The different degrees of freedom of the movement of the particles in solids, liquids and gases is clearly represented in the animations.

For this type of visual tool, pupils derive most value when it is incorporated into the lesson in an active way. Since there is no spoken commentary or prompting notes, the explanations have to be provided by the teacher or pupils. It may be used as a demonstration aid, or pupils working in small groups could take turns to provide a spoken commentary to the animations, or perhaps individual pupils might be set written tasks focusing on explaining the observed changes.

**Sample tasks:**
- Describe what you see when a lump of ice is heated in a beaker.
- Use the particle theory to explain the change.
- What are the similarities and differences between the particles in a solid, liquid and gas?
- Where in a liquid does evaporation take place?
- How does the particle theory help you understand how a liquid evaporates?
Case Study 6.3: Analysis of motion using video images

Learning objectives:
• to study the motion of a space shuttle at launch;
• to obtain and analyse distance–time and velocity–time graphs.

Added value:
• use video to investigate a phenomenon outside the laboratory;
• take measurements from the video to plot graphs of the motion.

In this example the program shows a video recording of the launch of a space shuttle. In a second window panel it allows a frame by frame analysis of the motion from which distance and time measurements can be taken and recorded.

In each still frame, a marker can be superimposed on the picture by pointing and clicking on any desired feature. In this case the nose cone of the rocket makes a suitable point with which to track the motion of the rocket. By adding a marker to a series of frames in succession, a trail of markers is built up. The increasing spaces between the markers clearly show the acceleration of the rocket (Fig. 6.3).

The program records the $x$ and $y$ coordinates for each marker position and accumulates these in a data table. It also calculates average velocities and accelerations in the $x$ and $y$ directions. Finally, at the click of a button, there is a choice of graph plots showing distance–time or velocity–time relationships.

The analysis of the motion in this example has a certain resemblance to stroboscopic photography and traditional tickertape methods, the essence of which is to mark the position of the moving object at regular time intervals. The spacing of the
images, dots or markers provides valuable information about the motion; large spaces indicate fast velocities, smaller spaces indicate slow velocities, increasing space size indicates acceleration and so on. The time between frames provides the time coordinates and allows velocity to be calculated.

Overall, this type of program presents a general technique for measuring the motion of any object recorded on video. It can be applied to video sequences recorded by pupils using a webcam or similar video camera. Being an 'open' tool-like program, it is necessary for pupils to be taught application skills to tease out the scientific significance of the measurements concerned. In this case, the upward curve of the distance–time graph indicates an increasing velocity. This is confirmed by the velocity–time graph which has an upward slope, but which is also linear, indicating a uniform acceleration. To help pupils think through the chain of connections and make links with the laws of motion, a guidance framework is needed. The common solution here is to provide a worksheet. The science underlying the measurement process itself is also worthy of study.

**Sample questions:**
- What is the time interval between each frame of the video sequence?
- What does the spacing of the markers suggest about the motion of the shuttle during take-off?
- What feature of the distance–time graph gives information about the velocity of the shuttle?
- Calculate the rate of acceleration of the shuttle from the velocity–time graph.
Chapter 7

Calculating, modelling and simulation tools

This group of software tools has a wide variety of application throughout the science curriculum at all levels. The basis for most software applications in this group is the computer's versatility as a calculating tool. Modern computers perform huge quantities of calculations at such incredible speeds that the effects appear instantaneous. Basic calculating facilities under user control are available in spreadsheets, data-logging and graphing programs. Modelling programs also allow user control over the definition of formulae but also provide more sophisticated means of display, sometimes with animated graphics. Simulations usually incorporate mathematical models for calculating results but without user control of the formulae in those models. The display is usually rich in animated graphics. All the tools in this group can be used to teach pupils to explore ideas. They are all interactive in the spirit of inviting pupils to be active, inputting values, observing consequences, reflecting on them and developing further ideas to test.

Recommended teaching usage:

- Exploring ideas; the learner as an explorer.

Features of calculating tools

A spreadsheet program is the most widely used software tool for calculations. Its universal presence in school curricula means that science teachers can usually be assured that pupils already possess operational skill with this type of program.

The program allows pupils to define precisely the required calculations using arithmetic and algebraic symbols. The data are organized in a matrix of cells in columns and rows and calculation formulae can be assigned to any cell or group of cells and can operate on data in any cell or group of cells. The versatility of this structure and the sophistication of the calculating tools available lend themselves to an enormous variety of applications, but it has to be said that the training investment to acquire sufficient operational skill to make the program perform the required task is considerable. Such is the usefulness of graphical facilities for
presenting the results, that graphs, bar charts and pie charts are common features of spreadsheet programs.

Data-logging and graphing programs also contain extensive calculating facilities. Since the main purpose of these programs is to facilitate the graphical presentation and analysis of data, their design is usually fine-tuned to make this activity as convenient as possible. For example, in a single operation, calculations can be performed on all the data items on a graph to yield results presented directly as a new graph. The graph is the main vehicle for viewing the data both before and after calculation. The tabular format, being redundant, can be eliminated from view altogether. Graphing programs have built-in calculating facilities for generating smooth curves, best fit curves and a variety of analysing tools with a great degree of user control. The following chapter on graphing software discusses these in more detail. For science teaching purposes, data-logging and graphing programs are often more convenient to use than spreadsheets and more conducive to exploratory activity because of the greater interactivity available in their analysis tools. Graphs generated by spreadsheets tend to be static, making them well suited to publishing activity but poor for exploring data.

Features of modelling tools

Superficially, many modelling activities with computers involve the manipulation of formulae and their subsequent use for calculation; a mathematical model is used in the first instance to describe a phenomenon and then to predict new information about the phenomenon. However, the purpose of modelling is to aid thinking about the phenomenon concerned and an essential aspect of the modelling process is to forge links between the phenomenon, previously understood principles and the model itself. A model may consist of one formula or a sequence of several interdependent formulae and it is often tested by comparing its calculated data with experimental data. A spreadsheet may be used for building the formulae and subsequently generating new data. However, a purpose-designed modelling program often makes a better educational tool. It needs to provide for building and editing sequences of formulae, the definition of initial parameters, the input of new values for parameters and facilities for graphical output. The ability to edit and alter the model are key features. The best modelling programs also offer animated graphics driven by the mathematical models. In some cases, iterative models are useful, whereby arithmetic calculations, based on first principles, are performed in incremental loops, whilst analytic models using linear sequences of formulae are suitable in many situations where invoking first principles might be considered clumsy.

Features of simulations

Simulations in software represent a step further than modelling in which the user interface (i.e. the appearance on the screen) is usually customized to the needs of the particular application. Unlike a modelling program, which is generic in character, simulations are designed to represent particular phenomena. A simulation usually does not provide access to the mathematical 'engine' built into the program, but does allow the user to supply parameters representing different conditions by which
editing can be observed without delay. Such saving of time and labour can support investigative work by reducing the delay in observing the consequence of testing an idea. Data-logging and graphing programs offer similar features for building formulae and generating derived data, but with the advantage that the results are promptly presented interactively as a graph.

![Figure 7.1 Dialogue box for building a formula (Insight 3, courtesy of Logotron)](image)

When multiple calculations are involved, spreadsheets are more reliable and consistent than manual methods. Assuming that formulae have been correctly defined and that values have been typed into the program accurately, calculations should be totally error-free. On occasions when entered data has been mistyped, the error should be traceable by virtue of the visibility of all the components of the calculation process. The visual layout of a spreadsheet is an important property which can be very useful in educational terms:

- through careful design it can assist the transparency of calculation processes;
- it can help pupils organize data in clear tabular structures;
- with suitable annotation, explanations of calculations can be superimposed on the spreadsheet; more elaborate textual additions can be used to create tutorials for helping pupils follow a process;
- pupils can be offered prepared templates which provide a ready-made structure for entering their own data into the spreadsheet.

Finally, the visual order of data can be modified by sorting operations (Fig. 7.2). Sorting facilities can reorganize columns of data into ascending or descending hierarchy, a useful tool for exploring patterns in sets of data.
Modelling as a process is essentially about describing phenomena in such a way that the phenomena become better understood. A broad view of modelling embraces theoretical models, conceptual models, visual models and analogies as well as mathematical models. Our attention here will be confined to the type of modelling which uses mathematical formulae, since this implementation on computers has the most common use in school science. The modelling process might begin with a formula or group of formulae which describe a phenomenon. The formulae representing the model can be used to generate 'synthetic' data about the phenomenon. In effect, the model permits 'virtual experiments' to be conducted on the computer. The acceptability of the model depends upon how well the virtual experiment matches or predicts behaviour observed in real experiments and the task for the pupil is an evaluative one. The great benefit of computer modelling is that pupils can easily explore alternative versions of a model by editing the formulae. As with calculating tools, the calculation 'engine' within the program performs all the calculation 'chores', freeing pupils to concentrate on strategic aspects of the model and interpretation of the data. The ease of manipulation and characteristic flexibility of software can be used to encourage pupils to try out different ideas and to take risks which might be unacceptable with real laboratory equipment.

It can be argued that curve-fitting facilities found in graphing programs can also be used as modelling tools since they help pupils test the validity of a formula for describing a given set of data. The most useful versions of curve-fitting tools allow pupils to choose first a general formula which the program then attempts to fit to the data and evaluates the constants. In the process of selecting the formula and evaluating the quality of the fit, pupils can apply their knowledge of the properties of straight line graphs and standard curves and attach significance to constants such as gradients, intercepts, indices and coefficients.

Computer simulations of experiments can be used for a variety of purposes, one of
which may be as a substitute for laboratory work! Hopefully, such extreme use occurs only in special circumstances and pupils are not routinely deprived of direct hands-on activity. However, as with other ICT tools, which appear to be replacements for conventional methods, it is important to have a clear vision of the particular advantages on offer. Sometimes there is a clear-cut case of the simulation representing an experiment which normally might be dangerous, inconvenient, time-consuming, difficult, or simply too expensive in terms of the required equipment. Relevant examples include experiments on radioisotopes, viruses, industrial processes, ecosystems, populations and food chains. In such cases simulations give access to phenomena beyond the normal resources of a school laboratory. Some simulations, such as those of electric circuits, provide enrichment of conventional laboratory work by extending the scope of experiments to include a wider range of components or variables.

Compared with real experiments, most simulations generate ‘clean’ data without the ‘noise’ usually associated with pupils’ readings or calculating errors, or with variables inadequately controlled in the experiment. The advantage of eliminating unwanted ‘clutter’ is to offer pupils the possibility of viewing a clear pattern of results, which can encourage them to draw desirable conclusions. For some teachers, this sort of stage management will be philosophically unacceptable, presenting pupils with an artificial image of reality and biasing their judgement. For others, the simulation is useful as a ‘nursery’ for building pupils’ confidence in preparation for the real world of experiments. This discussion will be developed further in the section on application skills.

There are occasions when issues of classroom procedure or management define useful purposes for simulations. Simulations can be useful in providing a tutorial for a real experiment, or as a revision of work previously done. Very little preparation is needed compared with real experiments and often time can be saved in obtaining a set of results.

In most simulation programs the results of multiple internal calculations are presented in the form of a graphical display. The more sophisticated modelling programs also offer graphical and animated image output. In such cases the calculation and graphical technologies combine to assist the visualization of sometimes abstract concepts. Examples include animated diagrams of wave phenomena (reflection, interference, diffraction etc.), the synthesis of waves from their harmonic components, models of radioactive decay, the simulation of molecular movement in liquids and gases, the growth and decay of populations, interactive diagrams to show the addition or resolution of forces in two-dimensional space.

A characteristic feature throughout this software group, as with many ICT applications, is that of offering pupils frequent and prompt feedback in an interactive manner. This offers considerable potential for providing positive reinforcement, motivation and for stimulating learning. The challenge for teachers is to approach the design of tasks in a way which exploits this potential.

Operational skills

These skills concern knowledge of the features in the software and how to use them. Amongst the group of software types considered in this chapter, modelling
programs and simulations contain so many features special to each application it is
inappropriate to make general statements about the necessary operational skills.
However, for spreadsheets, graphing and data-logging programs, there is a core of
common requirements which includes:

1. Data entry
   - In most instances pupils need to enter data via the keyboard; they may need
to use highlighting techniques.
   - Data can sometimes be transferred from other programs by copy and paste
operations.
   - Data may be loaded from files stored on a disk using the 'Open' option. It is
useful to understand that data files in the CSV (comma separated values)
file format are compatible with all types of data handling software.

2. Defining formulae
3. Plotting graphs, including using cursors, zoom, assigning axes, altering axes
   limits
4. Sorting data

Application skills

This group of software tools is very useful for supporting exploratory learning
activity in which pupils have a large measure of control and are required to make a
personal response. They mainly serve problems which can be expressed in numerical
terms. Pupils employ skills associated with testing, evaluating and adapting their
ideas. This is made possible through software facilities for editing calculations,
redefining formulae used in models and varying the parameters supplied to a
simulation.

Pupils begin to develop application skills when they have a secure foundation of
operational skills with the software. Then there are several distinct levels of
sophistication of use according to the degree of prescription implicit in the task.
As novices, pupils may begin at the first level and then progress to higher levels as
their skill develops. We will base the discussion of levels on the use of spreadsheets
and then relate the analysis to the use of graphing, modelling and simulation
tools.

Task Level 1. Exploring existing data
Here pupils are presented with a previously constructed spreadsheet, furnished with
a complete set of data. The activities use the spreadsheet tools to pick out salient
features or to look for patterns in the data using sorting and graphing facilities. The
design of the spreadsheet and the gathering of data are not part of the task; instead
the emphasis is on analysis of data.

Task Level 2. Adding new columns
Again pupils are presented with an existing spreadsheet complete with data, but the
task now requires pupils to develop its structure and define further calculations. This
will usually involve defining formulae to generate new data in further cells or
columns. Thus pupils start with a model spreadsheet, and engage with the process of design by building new features on to it.

**Task Level 3. Adding data to an empty template**

Here pupils are presented with a ready-built spreadsheet as a template in which, although the columns and formulae are defined, no data have yet been inserted. The task for pupils is to gather their own data and enter it into the 'empty' spreadsheet.

**Task Level 4. Designing a spreadsheet**

This is the most sophisticated level of use, requiring pupils to design their own spreadsheet layout, define formulae, enter all the data and analyse the data. It involves exercising all the skills represented in the previous levels.

In practice it is possible to set tasks which combine aspects of levels 1 to 3. The most important point we wish to make here is that each of the proposed levels implies a limited number of objectives requiring a similarly limited range of skill. In this way a progression in learning difficulty can be built. From a teaching stance, this is usually more satisfactory than introducing novice pupils to spreadsheets at level 4. Unfortunately the latter is often the entry level when confronted with a 'bare' spreadsheet program for the first time. Sample files and templates are required as support materials to allow other levels of use.

The same principles can be applied to the other types of program in this software group. Tasks with graphing programs at level 1 would only involve analysis of example data provided. Level 2 tasks would involve defining formulae to calculate new data, whilst level 3 tasks offer pupils a set of pre-defined graph axes ready for data insertion. At level 4, tasks would require pupils to define all the graph parameters, enter and analyse the data. Similarly, tasks with modelling programs can be designed at levels 1, 2 and 4. Simulations, on the other hand, generally only have one level of use, defined by the customization to the topic concerned. An overview of task levels is presented in Table 7.2.

**Table 7.2 Overview of task levels**

<table>
<thead>
<tr>
<th>Task Level</th>
<th>Spreadsheet</th>
<th>Graphing</th>
<th>Modelling</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Explore existing data</td>
<td>Explore existing data on graph</td>
<td>Use a pre-built model</td>
<td>Use the simulation as presented</td>
</tr>
<tr>
<td>2</td>
<td>Add new columns to calculate new data</td>
<td>Calculate and plot new sets of data</td>
<td>Add new formulae to or edit an existing model</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>Add data to an empty template</td>
<td>Add data to pre-defined axes</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>4</td>
<td>Design spreadsheet Enter data Analyse data</td>
<td>Define graph axes Plot data Analyse data</td>
<td>Build model Generate data Evaluate data</td>
<td>—</td>
</tr>
</tbody>
</table>
Using the time bonus
The property of performing rapid calculations runs through this software group. The consequent prompt presentation of results delivers a time bonus, which can be useful in the modern context of congested curricula. It is important to remember that there are varied demands upon teaching time and that, in a balanced sequence of lessons, the time spent on activities which introduce new ideas to pupils only occupies a certain proportion of the total time teachers spend with their pupils; pupils also need opportunities for practice, reinforcement, enrichment and revision. In this spirit, the time bonus accruing from software use may be employed in two main ways:

1. To repeat tasks or perform more of them;
2. To reflect on the task, focusing on interpreting the results.

In either case, guidance from the teacher is a likely necessity. Repetition needs a purpose, which, for example, may be to check the validity of a result, to explore the effect of changing parameters, to challenge pupils’ understanding or to remind pupils of previous learning. Reflection and interpretation can be made more effective when pupils are prompted to make links with their previous knowledge. Teachers are in the best position to decide what sort of support framework is needed by their pupils. The use of worksheets, direct teacher intervention or a combination of both are the most obvious methods but, as has been noted above, template files with partially built spreadsheets or models are often useful for providing a guidance structure.

Investigative approaches to modelling
In general terms, investigative work in science involves pupils in identifying a problem; deciding what to do and how to do it; carrying out the task; collecting data; analysing and interpreting data; evaluating their investigation and drawing conclusions; and reporting on their findings. A theme which underpins investigative approaches is that pupils are required to draw on previous knowledge as they make decisions that shape their inquiry. We will consider some aspects of that knowledge which are special to mathematical modelling.

In any modelling activity, whether pupils build their own model or edit or use a pre-built model, it is fundamental that they should have a clear understanding of the variables involved in the problem. These have several aspects:

1. The variables represented by algebraic terms in formulae need to be identified and associated with the phenomena they represent;
2. The distinction between independently controllable variables and dependent variables needs to be made;
3. Some variables should be recognized as compound variables, derived by calculation from primary variables;
4. The numerical range of data for each variable needs to be estimated.

Having addressed the above issues, the modelling process then requires pupils to use their knowledge about the variables to relate them to each other with suitable
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formulae. Some formulae define variables whilst others describe relationships between variables. (For example ‘\( v = \frac{s}{t} \)’ defines velocity, whereas ‘\( F = ma \)’ describes a relationship between force, mass and acceleration.) It is important to appreciate this distinction in status of different formulae and it is also helpful to understand the characteristic properties of relational formulae (for example, the difference between direct proportion and inverse proportion for describing how two variables depend upon each other). Throughout the process of building a model, the importance of keeping in view the scientific principles that underpin the formulae cannot be over-emphasized. Pupils can soon lose their way if they manipulate formulae merely using mathematical rules alone.

When a model is built, pupils use it to generate numerical data and they have to make choices about the mode of presentation of the data. Tables of data, although most easily generated, are often the least useful for spotting patterns and trends. Graphs and charts are usually the preferred options. Pupils need to consider the appropriateness of pie charts, barcharts or \( XY \) graphs (referred to as ‘scattergraphs’ in many programs). For the latter, decisions have to be made about the assignment of the axes, and sometimes the scales and limits. More advanced modelling packages also display output through animated graphics which are ‘driven’ by the model. The investigation proceeds by testing the model through a process of evaluating the output data, comparing it with predictions or with experimental data, identifying anomalies and modifying the model in the light of the evaluation. Such evaluation needs to draw upon pupils’ scientific knowledge and understanding to interpret the data and draw conclusions. Through an iterative process of predicting, testing, evaluating and modifying models, pupils can explore alternative models or versions of models.

Care is needed to minimize a methodology which uses mere trial and error. At all stages it is important for pupils to think about the links between the model and the real phenomenon so that their exploration is guided by a rationale. To be useful, the predictions from the model also need careful reflection. As noted above, such thoughtful engagement usually needs prompting by the teacher through direct intervention or with conventional worksheets or on-screen aids.

Making the most of simulations

The above discussion of investigative approaches can often be applied to the use of simulations. At their very best, simulations can provide visualisation of difficult concepts or give access to experimenting not normally possible under classroom conditions, but their value is likely to be weakened if pupils simply explore all the available options in an arbitrary way. As with any practical laboratory activity, the ever-present challenge for the teacher lies in how to engage pupils’ thinking so that there is a strong coupling between ‘hands’ and ‘mind’. There is a certain role for unstructured exploratory activity in a preliminary fashion for providing stimulus and aiding familiarization, but it should invariably lead on to clearly targeted tasks with identified objectives. If a truly investigative approach is adopted, then pupils should participate in the process of defining objectives.

In our previous discussion we recognized that simulations can usually be relied upon to yield ‘clean’ data, unblemished by reading errors or from inadequately controlled variables. This can be very useful for guiding the development of pupils'
Calculating and modelling tools

confidence in handling variables and analysing results, particularly in situations where the equivalent real experiment would be impossible to conduct in the school laboratory. However, it is important to acknowledge that the generation of data is 'stage managed' and that the synthetic data is only as good as the model employed in the program. Sometimes there are limitations due to approximations within the model. Often a model assumes certain simplifications because the true number of variables involved is unknown or difficult to incorporate into the model. Such acknowledgement is more desirable than the dishonesty which sometimes attends conventional practical work when pupils are expected to draw instructive conclusions from poorly collected data or even falsified data (Barton, 1998, p. 238). However, if simulations are to be successful in helping pupils to progress to understand phenomena and identify patterns in real data, clearly teachers need to prepare pupils for the untidiness of real data and help them to understand the reasons for variability and errors. The similarities and differences between real and simulated data can be used to prompt critical evaluation and further exploratory activity. The whole spirit of using simulations should encourage analytical and divergent thinking.

Case Study 7.1: Calculations of food values for a pizza

Learning objectives:
• to calculate the nutrient content and energy content of a pizza for a given selection of ingredients;
• to design recipes for a variety of different nutrition and energy needs.

Added value:
• automatic calculation of data;
• sorting of data.

This example uses a spreadsheet to calculate the energy content, protein content, fat content and carbohydrate content of a pizza according to the choice of ingredients in the topping. The calculations are then used to find the optimum ingredients fulfilling the needs of people with different activity levels.

The spreadsheet is set up as in Figure 7.3. For each ingredient columns C, D, E and F contain numerical information showing the energy per gram, protein per gram, fat per gram and carbohydrate per gram. These are standard values obtained from food data tables. Column B allows the pupil to type in the mass of each ingredient. Pupils are free to choose which ingredients they want by typing in a mass for each or leaving a mass cell blank. Column G shows the total energy and columns H, I and J show the total amounts of each type of nutrient in the pizza. The program calculates these values according to the formulae specified for each of these columns. For example column G calculates energy content using a formula of the form \( \text{SUM}(G5:G15) \).

Activities using this data are best presented at task level 1, such that pupils are presented with a completely built spreadsheet including data. Other task levels are possible, but if the main objective is to calculate new information and evaluate it,
Activity 1. Sorting ingredients
The ingredients are sorted in order of their energy, protein, fat or carbohydrate content by highlighting the appropriate cells of the sheet and invoking the 'Sort...' option. The sorted data makes it easy to see which ingredients are 'best' or 'worst' for supplying each nutrient or energy.

Activity 2. Design a pizza
To see how the sheet works, pupils can be given a sample recipe with the ingredients' masses already specified. The recipe can be modified by altering the appropriate value in the mass column. Alternatively, pupils simply type a value in the mass column for each ingredient they wish to include in their pizza recipe. In all cases the program automatically calculates the nutrient contents and totals.

Activity 3. Compare nutritional needs
Pupils can be given several pizza recipes, asked to use the spreadsheet to calculate the nutritional details and evaluate each recipe by its overall nutritional content. The nutritional and energy needs of people vary according to their age and activity level and each recipe can be evaluated for its suitability in satisfying the needs of a particular group. For example, a high carbohydrate content is useful for an adult in a physical occupation which demands the ready availability of energy, whereas protein might be a higher priority for a growing teenager. Pupils can be asked to design their own recipe for a particular activity group.
Clearly the spreadsheet is merely a calculating tool and it is necessary for teachers to support pupils in understanding the significance of the different nutrients and how the calculations can be used to make judgements about the suitability of their choices of ingredients.

**Case Study 7.2: Calculating stopping distances of motor cars**

**Learning objective:**
• to describe the connection between the speed of a motor car and the minimum stopping distance when the brakes are applied.

**Added value:**
• automatic calculation of data;
• calculations are presented in stages;
• prompt graph display;
• analysis of graph.

This example illustrates how several formulae are combined to calculate a series of results using a spreadsheet. The variables considered are:

• speed of car;
• driver’s reaction time;
• thinking distance;
• braking distance;
• total stopping distance.

The model for calculating the total stopping distance consists of adding the two components: thinking distance and braking distance. The *thinking distance* is the distance travelled whilst the driver reacts to the situation and the actual *braking distance* is that travelled whilst the brake pedal is depressed (Fig. 7.4).

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Speed</td>
<td>Speed</td>
<td>Thinking distance</td>
<td>Braking distance</td>
</tr>
<tr>
<td>2</td>
<td>m.p.h</td>
<td>m/s</td>
<td>m</td>
<td>m</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>4.5</td>
<td>2.7</td>
<td>1.4</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>9</td>
<td>5.4</td>
<td>5.8</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
<td>13.5</td>
<td>8.1</td>
<td>13.0</td>
</tr>
<tr>
<td>6</td>
<td>40</td>
<td>18</td>
<td>10.8</td>
<td>23.1</td>
</tr>
<tr>
<td>7</td>
<td>50</td>
<td>22.5</td>
<td>13.5</td>
<td>36.2</td>
</tr>
<tr>
<td>8</td>
<td>60</td>
<td>27</td>
<td>16.2</td>
<td>52.1</td>
</tr>
<tr>
<td>9</td>
<td>70</td>
<td>31.5</td>
<td>18.9</td>
<td>70.9</td>
</tr>
<tr>
<td>10</td>
<td>80</td>
<td>36</td>
<td>21.6</td>
<td>92.6</td>
</tr>
<tr>
<td>11</td>
<td>90</td>
<td>40.5</td>
<td>24.3</td>
<td>117.2</td>
</tr>
<tr>
<td>12</td>
<td>100</td>
<td>45</td>
<td>27</td>
<td>144.6</td>
</tr>
</tbody>
</table>

**Figure 7.4** Spreadsheet for calculating stopping distances of motor cars (Insight 3, courtesy of Logotron)
Speed is chosen as the independent variable and a series of values from 10 to 100 m.p.h are entered in column A. The further stages in the calculation are built up in the other columns as follows:

**Column B**: The speed is calculated in m/s. The conversion of speed units is achieved by defining one formula \( \text{speed} \times 0.45 \) for the whole column.

**Column C**: Thinking distance is calculated using the formula \( \text{speed} \times \text{reaction time} \). A value for the reaction time must be chosen; 0.6 seconds is an appropriate choice.

**Column D**: Braking distance is calculated using the formula \( \text{speed} \times \text{speed} / 2 / \text{deceleration} \). A value for the deceleration must be chosen; 7 m/s/s is an appropriate choice.

**Column E**: Total stopping distance is calculated using the formula \( \text{thinking distance} + \text{braking distance} \).

This exercise could be presented to pupils at any of the four task levels identified in the previous discussion. At task level 1, a fully constructed spreadsheet complete with data could be explored. One of the most significant features is revealed by plotting a graph of stopping distance against speed, which shows a non-linear upward trend. Pupils could also experiment with the effect of altering the reaction time to simulate a tired driver or vary the value used for acceleration to reflect different road surfaces. At task levels 2, 3 and 4, pupils need to think about the variables and the physical principles needed to define the formulae required in each column; the ‘thinking time’ formula springs directly from first principles relating speed to distance and time; the braking time is more subtle in that it requires thought about deceleration and its relationship with the initial and final speeds \( v^2 - u^2 = 2as \).

The design of the spreadsheet provides a very useful framework for structuring the sequence of calculations involved in this exercise with a separate column for each variable. Although it would be possible to define a single formula to calculate the stopping distance directly from the speed, the staged structure of the calculations described above is a much more effective aid to understanding.

**Case Study 7.3: Calculations on data to investigate Boyle’s Law**

**Learning objective:**
- to understand the relationship between the pressure and volume of a fixed mass of gas at a constant temperature.

**Added value:**
- automatic calculation of data;
- prompt graph display;
- analysis of graph.

This example uses a spreadsheet to explore the relationship between the two
variables *pressure* and *volume* of a gas. The data is collected from a laboratory experiment in which a fixed mass of air in a strong glass tube is squeezed by pumping oil into the tube. The pressure of the air is measured with a bourdon gauge. The confinement of the air ensures that the mass is constant and the expansion is controlled very slowly to maintain a constant *temperature*. Thus only *pressure* and *volume* are allowed to change. Data for these variables are entered into columns A and B of the spreadsheet. The relationship between them can be explored in three possible ways.

**Method 1**
Plot a graph of *pressure* vs. *volume*. The program is then used to plot a ‘best fit’ curve through the points. The resulting curve shows a downward trend which matches the observation that the pressure is smaller for larger volumes (Fig. 7.5). The program calculates the parameters in the best fit formulae which turns out to be ‘pressure = 52 × volume⁻¹’, indicating that the pressure varies in inverse proportion with the volume.

![Figure 7.5 Spreadsheet and graph for investigating relationship between pressure and volume of a gas (Insight 3, courtesy of Logotron)](image)

**Method 2**
Use column C to calculate 1/volume. Inspection of the new set of values reveals that they increase as pressure increases. When the graph of *pressure* vs. 1/volume is plotted, the result is a straight line passing through the origin and sloping upwards. Thus linear proportion is confirmed. Using the program’s ‘best fit’ curve facility, the formula for the line is evaluated as ‘pressure = 52/ volume’, confirming the result of the first method.

**Method 3**
Use column D to calculate pressure × volume. Inspection of the new set of values
reveals that they span a very narrow range from 49.8 to 51.2. Thus the values of pressure $\times$ volume are constant within one per cent, verifying the usual expression of Boyle's Law: 'pressure $\times$ volume = constant'.

The third method is the ICT equivalent of the most commonly used manual method for analysing the data on paper. Clearly, the use of the spreadsheet speeds up the calculation process considerably and offers a time bonus. This could be spent on more discussion of the results, or pupils could be encouraged to try the other methods and think about the reasons for their equivalence. Method 2 is based on the traditional straight line method for identifying a relationship. Method 1 only becomes feasible with graphing software which calculates the best fit curve. All three methods can be presented to pupils at Task Levels 1, 2, 3 or 4.

Case Study 7.4: Modelling the heat losses in a house

Learning objective:
- to identify the contributions of different sources of heat loss in a house and study the effectiveness of various methods of thermal insulation.

Added value:
- automatic calculation of data;
- many variables accommodated;
- calculations presented in stages.

This example illustrates how a mathematical model can be built by combining several formulae in a spreadsheet. The model is used to calculate the heat loss from each surface of the house and then the total heat loss from the whole house. The calculations are used to study the contribution of each surface to the overall loss and the effect of introducing different types of thermal insulation.

The spreadsheet is very useful for handling the many variables involved in the problem. The variables identified are:
- type of surface: loft, walls, windows, floor, draught;
- loss factor for each type of surface;
- area of each surface;
- temperature difference between inside and outside of house.

The model assumes that the heat losses for each surface depend in proportion to the area of the surface and the difference in temperature between the inside and outside of the house. The 'loss factor' for each surface represents the energy transferred in one second by one square metre of the material when the temperature difference is one degree. Multiplying the loss factor by the area and temperature difference gives the heat loss for the surface in watts. The model is as follows:

Total heat loss = [(area $\times$ loss factor)loft + (area $\times$ loss factor)floor + (area $\times$ loss factor)walls + (area $\times$ loss factor)windows + (area $\times$ loss factor)draughts] $\times$ temperature difference
The spreadsheet is set up as in Figure 7.6. Columns B and C simply contain information about the loss factors for each surface, with and without insulation. The data in these columns is for reference only. Pupils need to choose from either column a loss factor for each surface and type the value in column D. They must also decide upon a value for the area of each surface and type it into column E. The program calculates the heat loss per degree temperature difference in column F using a formula of the form ‘= D4*E4’. The sum of all the values in column F is calculated in F10 using the formula ‘= SUM(F4:F8)’. Pupils need to type in the difference between the inside and outside temperatures in cell F12. The program uses the values in F10 and F12 to calculate the total heat loss for the house in F14 using the formula ‘= F10*F12’.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>Loss factor info.</td>
<td>Loss factor info.</td>
<td>Loss factor</td>
<td>Area</td>
<td>Heat loss</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>No insulation</td>
<td>With insulation</td>
<td>W/m²/degC</td>
<td>m²</td>
<td>W/degC</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Loft</td>
<td>1.5 (100mm fibre)</td>
<td>0.3</td>
<td>40</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Walls</td>
<td>2.1 (cavity filled)</td>
<td>0.5</td>
<td>200</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Floor</td>
<td>0.61 (carpet)</td>
<td>0.59</td>
<td>40</td>
<td>23.6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Windows</td>
<td>5.6 (double glazed)</td>
<td>3.2</td>
<td>10</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Draughts</td>
<td>1.5 (good proofing)</td>
<td>0.6</td>
<td>10</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Total heat loss per degC 172.6

Inside/outside temperature difference 5

Total heat loss 863 watt

Figure 7.6 Spreadsheet for modelling heat losses in a house

Activities with this spreadsheet levels can be presented at any of the task levels proposed previously.

Task Level I activity: Investigating the model

This activity invites pupils to investigate the fully built spreadsheet. All the data are present and the model defined, so the focus of the activity is on using the model to test ideas about how the heat losses depend upon the different variables. Pupils need to type in some values of their own; for example, they can type in a new value for the temperature difference, or the area of the windows, and observe the effect on the total heat loss. They can change a loss factor value in column D to simulate the effect of adding or removing the insulation for a particular surface. They could predict the effect of opening a window or a door. They might be prompted to think about relative losses due to the different surfaces. There are so many possibilities for investigation, pupils need a worksheet for guidance or consultation with their teacher to define useful targets for their activity. The spreadsheet format is so useful for following the individual steps in the calculations, that pupils' attention should be drawn to this feature.
Task level 2 activity: Improving and refining the model
The simple model is useful for getting pupils started, but there are many opportunities for extending the model. For example:

- add a column to calculate the losses at each surface as a percentage of the total loss;
- add cells to calculate the financial cost of the losses;
- present the losses in the form of a pie chart or bar chart.

The limitations of the mathematical model might also be considered. Simple proportion was assumed for all the calculations implicit in the model but, for some surfaces, the relationship between heat loss and area might be more complex. To explore this, the formulae for calculating column F need modification.

Task level 3 activity: Developing a model from a template
Instead of presenting pupils with the completed spreadsheet, the same structure of headings and formula definitions could be retained, but with the data omitted. The first task for pupils would be to research elsewhere to find suitable data for loss factors and areas of surfaces and then insert them into the table. For example, pupils might obtain measurements of their own homes. Having completed the table, the previous activities are applicable.

Task level 4 activity: Designing a model from a brief
This involves starting with a clear spreadsheet and defining columns and rows for all the elements needed for the calculations. As usual, this is the most sophisticated level of use and pupils needs a good level of confidence and skill to succeed. A thoroughly prepared design brief, outlining the problem and prompting useful strategies, is essential.

Sample questions and tasks:
- What is the average temperature inside your house during the winter?
- What is the typical outdoor temperature during the winter?
- Survey the methods of thermal insulation in your house and use the model to calculate the amount of heat lost on a typical winter day.
- Compare the effectiveness of different methods of insulating a house.

Case Study 7.5: Modelling a radioactive decay series

Learning objective:
- to study the growth and decay of isotopes in a radioactive decay series.

Added value:
- automatic calculation of data;
- many variables accommodated;
- graphical display.
This example illustrates how a mathematical model can be built using a set of formulae in a data-logging program. The model is used to calculate the remaining amount of each isotope in a radioactive series in which an unstable isotope decays to produce a further unstable isotope, which in turn decays to another and so on. The results of the parallel calculations are presented on a graph for easy comparison.

The data-logging program is very useful in providing an interactive graphical display of the results; being driven directly by the formulae in the model, the graph responds immediately to any changes made to the formulae.

Before the mathematical model can be built and used, pupils need to understand the physical process: The nucleus of an unstable isotope 'A' decays to give a new unstable isotope 'B'. As this process proceeds, the quantity of B gradually increases, but because B is also unstable, it decays to a further isotope 'C'. Thus the quantity of B goes into decline as the quantity of C grows. If C is also unstable, its quantity also declines. The model attempts to calculate the quantities of each isotope left at any time during the periods of growth and decline, taking account of the fact that the rate of decay is different for each isotope. The numerous calculations involved make this an ideal job for a data-logging program that is designed to handle continuous streams of data.

At the beginning, the amount of isotope A is 'A₀' but after a certain time, the amount left is given by:

\[ A = A₀ \times \exp (-rate_A \times time). \]

The amount of isotope B produced at any time is 'B = A₀ - A', but since this decays, the amount of B left after a certain time is given by:

\[ B = (A₀ - A) \times \exp (-rate_B \times time). \]

By a similar argument the amount of isotope C left is given by:

\[ C = (A₀ - A - B) \times \exp (-rate_C \times time). \]

These three formulae represent a mathematical model of the process. They are entered into the program which plots a graph for each isotope (Fig. 7.7).

Pupils can observe the graphs of the growth and decline of isotopes B and C. They can vary the model by adjusting the values of rateₐ, rateₙ and rateₜ to see how the shapes of the graphs are affected by the relative rates of decay for the three isotopes.

**Sample questions**

What happens to the amount of isotope B present if A decays quickly but B decays slowly?

How does this affect the amount of C present in the sample?
Case Study 7.6: Simulation of a food web

Learning objective:
- to observe changes in the populations of creatures contained within a food web.

Added value:
- virtual experiment, involving difficult measurements over long timescales;
- visualization of difficult concept.

This simulation allows pupils to study the growth and decline of populations in a food web.

This type of study is normally dependent on fixed sets of secondary data gathered over extended periods of time. The simulation potentially offers a range of data produced over a wide range of theoretical conditions and opens up a realistic possibility of investigating the effect of different variables on each other.

The components of the food web considered in this example are foxes, owls, rabbits, field mice and grass. The dependencies are shown in Figure 7.8. Pupils can set up the initial values of each population or use the default values in the program. The average daylight can be controlled to simulate the effect of different seasons. There is choice of display formats showing a statistical display, a graph against time or a graphical display with magnitude bars. When the simulation is set running, the calculations predict the population values at one year intervals. If preferred, values for the biomass of each component can be shown instead.
The default values provide a good starting point for investigation. If the population levels are studied for the first ten years a pattern soon emerges between the number of field mice and the amount of grass. Growth in the mice population gradually depletes the grass but, as this causes fewer mice to survive and reproduce, the grass begins to recover, and so the cycle repeats. Most relationships reveal a cyclic pattern accompanied by a time lag. When pupils have gained an operational understanding of the program they can attempt a variety of investigations, such as:

- setting new initial population numbers, possibly removing one element in the web;
- simulating the sudden decline in a population as might be caused by disease or a cull;
- studying the recovery of a population after a sudden decline;
- varying the average sunlight to simulate the effect of seasonal variation;
- considering the effect of the reproduction cycle or hibernation tendencies;
- comparing the trends in biomass with the corresponding population values.

This type of software tool only conveys meaning when the activity is embedded in a supportive theoretical framework, so there is a clear role for the teacher here to ensure that there are sound links with the theory. The behaviour of the simulation and the integrity of the results are entirely dependent on the quality of the internal mathematical models and implicit assumptions about the relationships between the variables. However, the compression of the timescale for the investigations allows pupils to begin to address an important topic containing subtle inter-dependencies.
Case Study 7.7: Simulation of terminal velocity

Learning objective:
• to understand how the forces of propulsion and friction acting on a bicycle affect its motion.

Added value:
• virtual experiment, involving difficult measurements;
• numerous rapid calculations;
• several variables accommodated.

This simulation allows pupils to investigate the factors affecting the motion of a bicycle. The program presents a scenario in which several parameters can be controlled and their effects observed in an animated graphics window and a graph of the velocity against time. See Figure 7.9.

Figure 7.9 Simulation of terminal velocity (Multimedia Science School © 2000 New Media Press Ltd)

The key issue for investigation is the balance of the forces on the bicycle when it is moving at a steady speed. There are several observations which seek explanations:

• starting from rest, a certain pedalling force is needed to get moving;
• the pedalling force to maintain uniform velocity is generally less than the initial starting force;
• reducing the pedalling force results in slowing down;
Calculating and modelling tools

• increasing the pedalling force results in an increase of velocity, but there is a limit to this increase such that a new uniform velocity becomes established.

The simulation program can be used to investigate these observations. The variables and parameters controllable by the pupil are:

• force on the pedals;
• angle of the road (uphill, level, downhill);
• type of bicycle frame (mountain bike, racer, recumbent).

The mathematical model built into the program calculates as a function of time the friction forces (mainly due to air resistance), total propulsion force, resultant force, acceleration and velocity.

Activity 1. Study the forces
When the simulation begins, pupils should study the animated graphics window to observe the magnitudes of the pedalling and friction forces shown as arrows superimposed on the picture. Whilst the pedalling force remains constant, the friction force gradually increases as the bicycle gathers speed. As the difference between the two forces diminishes, the graph shows the velocity increasing at a diminishing rate. This is the heart of the simulation, showing how terminal velocity is reached when the force of friction balances the cyclist’s pedalling force.

Activity 2. What determines the magnitude of the terminal velocity?
To investigate this question, pupils have two ways of altering the magnitude of the propulsion force; they can either specify a larger pedalling force or change the angle of the road. In either case the new propulsion force is indicated in the animated picture and the new terminal velocity is established when the opposing forces are in balance again. As a general rule, a larger propulsion force results in a larger terminal velocity. Pupils can also study how the type of bicycle affects this rule.

Activity 3. Changing the conditions during motion
Having obtained a basic grasp of the principles leading to the establishment of terminal velocity, pupils can be asked to consider or invent for investigation a variety of ‘What if . . . ?’ scenarios. For example, ‘What happens to the speed if the cyclist pedals harder for a few seconds and then resumes the initial pedalling force?’ or ‘What force is needed to maintain the same velocity if the road suddenly slopes uphill?’ There is a strong temptation to base predictions on everyday experience. The challenge for pupils is to predict and explain the scenario using the physics of forces and motion.

This simulation is a good example of performing a virtual experiment which would be very difficult in real practice. (The measurement of speed might be easy enough, but the measurement of pedalling force is very difficult and friction forces could only be calculated from the motion.) The simulation calculates ‘clean’ data, as one would expect from an idealized mathematical model, however, from a learning point of view, this serves to clarify and build pupils’ confidence in the relationship
between the forces and motion. The coordination between the labelled arrows in the animated picture and the graph display is a further aid to understanding the principles involved.

Sample questions and tasks:

- What can you say about the forces on a bicycle which is speeding up?
- In general terms, describe the relationship between the friction experienced by a bicycle and the speed it is travelling.
- What is the minimum time needed to reach a speed of 10 m/s from rest?
- Explain why different types of bicycle reach different terminal velocities with the same pedalling force.
Graphing tools

Graphs are a major tool for presenting and processing information in science and their role is enhanced when they are generated by computer software. The most significant feature of computer graphs is that they can be created during the process of data collection (in 'real time') or promptly after data collection. This transforms the status of the graph from a static visualization of collected data into a dynamic tool for exploring the data. In traditional use, a graph is often an endpoint of pupil activity, with the graph being constructed towards the end of a lesson of activity dominated by the collating and recording of measurements. In contrast, the computer graph provides a starting point for analysing the data. The best examples of graphing software offer a variety of analysing tools and other facilities for manipulating the plotting of the data.

Recommended teaching usage:

- exploring ideas; the learner as an explorer;
- collating and recording; the learner as a receiver;
- presenting and reporting; the learner as a creator.

Features of graphing software

Bar charts and \( XY \) line graphs are probably the most common types of graph in use in science teaching and these are replicated by many software graphing packages. Although we recognize that there are endless varieties of graph types and presentations available as a result of software manipulations, the discussion here will mainly focus on \( XY \) line graphs because of their versatility and importance to science. The main principle to be pursued is that, on the computer, the graph is not just an image to be looked at, but is something to manipulate and explore. Graphing software can be free-standing or an extension facility of a spreadsheet or data-logging package. In the case of data-logging software the graph has developed to occupy a major role in analysing the gathered data and many of the exploration features described here are most highly developed in this type of
software. However, data-logging is only one example of collecting scientific data. The variety of sources includes:

- data from experiments, collected manually;
- data from experiments, collected with a data-logger, automatically shown as graph;
- data stored in a spreadsheet;
- data stored in a database;
- data stored in a table;
- data collected from the internet.

The opportunities for manipulating and analysing data are essentially independent of the source of data, although the methods of entering each type of data into the graphing program will vary. (These are considered in the later section on ‘Operational skills’.) Once the data is entered, the program plots it accurately and speedily. The assignment of variables to the $X$ and $Y$ axes is readily made or altered. The axes limits and plotting scales are easily adjusted. Different sets of data can be colour-coded. The data can be plotted as points or lines or both. The lines can be simple point-to-point joins, smooth curves or lines of best fit. There is great versatility in choosing or altering how the data may be viewed, but this is only the beginning; a valuable range of labour-saving tools is usually available for examining the data and exploring its properties in greater detail. The most common tools include the following:

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zoom</td>
<td>To magnify a chosen portion of the graph and rescale the axes.</td>
</tr>
<tr>
<td>Cursors</td>
<td>For obtaining and comparing values from the graph.</td>
</tr>
<tr>
<td>Bar display</td>
<td>To illustrate relative magnitudes of values and rates of change.</td>
</tr>
<tr>
<td>Analysing aids</td>
<td>For calculating numerical features (such as change, interval, ratio, gradient, area) of the data from the graph.</td>
</tr>
<tr>
<td>Curve fitting</td>
<td>To identify and describe a trend within discrete measurements.</td>
</tr>
<tr>
<td>Define data</td>
<td>For calculating derived data to reveal relationships.</td>
</tr>
</tbody>
</table>

These tools have evolved to serve useful explorations of the data and their use will be illustrated in the case studies which follow. The guiding principles for their use need to be related to the general purposes of graphs in school science:

- A graph provides a **summary view** of a large amount of data. The shape of a graph communicates a pattern or trend in the data much more readily than a tabulated list of values. The graph ‘tells a story’ in a symbolic fashion.
- A graph is useful for **comparing** data as single items or in sets or groups. The relative magnitudes of data are made visible.
- A graph is useful for **studying changes** in data. The direction and rate of change is indicated by the slope of a line.
- A graph can be used to look for or test a **relationship** between variables. When one variable is plotted against another, significance can be attached to the fact that the resulting line is straight or curved.
- Exploring a graph line in detail reveals **properties** of data. Each graph shape has
characteristic and predictable properties; mathematical predictions from straight-line graphs are easily made, but predictions from quadratics and inverse squares are also possible.

In considering how the tools of software graphing packages can be usefully employed, these purposes will be reviewed and linked with ideas for pupils’ activity. But first let us think about the ‘added value’ of the computer method.

**Added value**

The advantages of computer graphs will be considered by distinguishing between the properties of software features and the benefits to learning which might flow from each feature. For ease of discussion, the properties have been grouped as shown in Table 8.1.

**Table 8.1 Properties and potential benefits of computer graphs**

<table>
<thead>
<tr>
<th>Properties of computer graphs</th>
<th>Potential benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plotting process is automatic</td>
<td>• low skill level required;</td>
</tr>
<tr>
<td></td>
<td>• improved plotting accuracy;</td>
</tr>
<tr>
<td></td>
<td>• time saved.</td>
</tr>
<tr>
<td>Immediate display (during data-logging)</td>
<td>• graph features may be readily associated with the phenomena producing the graph;</td>
</tr>
<tr>
<td></td>
<td>• a qualitative view of the data can precede quantitative description.</td>
</tr>
<tr>
<td>Easily manipulated (Axes can be rescaled or reassigned to different variables. Calculations can be performed on ‘raw’ data.)</td>
<td>• many alternative views of the data may be created. Small features may be magnified;</td>
</tr>
<tr>
<td></td>
<td>• relationships between variables may be explored;</td>
</tr>
<tr>
<td></td>
<td>• new secondary data may be calculated and plotted.</td>
</tr>
<tr>
<td>A variety of formats is available (colour coding, charts, line graphs, best fit)</td>
<td>• graphs may be overlaid for easy comparison;</td>
</tr>
<tr>
<td></td>
<td>• patterns and trends in data can be evaluated.</td>
</tr>
</tbody>
</table>

As with many software tools, the list of benefits must be qualified as ‘potential’ because a particular property can only deliver a benefit if it matches an identified teaching purpose and is exploited in a suitable context of activity. Purpose and manner of use are crucial factors in conveying ‘benefits’. For example, automatic plotting offers no benefit at all if the pupil is thereby deprived of learning basic plotting skills, but the same property enables pupils to plot many graphs in succession, allowing the repetition of an experiment under different conditions or experimenting with plotting alternative versions of the graph. For less able pupils, who might normally struggle to produce an accurate graph, automatic plotting can boost their confidence in using the graph as a tool for visualizing and interpreting
data. It is desirable for all pupils to have an experience of both manual methods and computer methods of graphing. We are strongly of the view that both methods can deliver benefits which are complementary to each other, but it is for teachers to decide an appropriate balance between the two. Manual methods might be used as an introduction to computer graphs, but these roles can easily be reversed with surprising results in motivation and understanding. Barton has demonstrated that computer graphs can be powerful tools for aiding discussion and thinking about phenomena (Barton, 1997).

Again, the time saved when the computer is used to plot the graph is of no benefit unless that time is redeployed profitably. Our hope is that the time bonus is spent on using the variety of methods for analysing and manipulating the data. Sometimes pupils can tackle tasks that are normally too difficult or tedious to perform; for example in making multiple calculations or transformations of data. There are many such opportunities for extending able pupils. Less able pupils are also supported in routine tasks; for example, reading information from graphs is less prone to errors than with paper and pencil methods. Whatever that task, there is an ever-present role for teachers in designing tasks suited to their pupils' particular needs, setting targets, monitoring progress, giving hints and prompts. The teacher's skills in asking key questions, encouraging pupils to ask questions and prompting discussion all contribute to successful application of the computer tool. Before we discuss ideas about pupils developing application skills with graphing software, we need to consider the basic repertoire of operational skills needed for using this type of software.

**Operational skills for software graphing**

These skills concern knowledge of the features in the software and how to use them:

- **Data entry:**
  1. In some instances pupils need to enter data via the keyboard; they may need to use highlighting techniques.
  2. Data can sometimes be transferred from other programs by copy and paste operations.
  3. Data-logging programs usually provide automatic plotting of the data.
  4. Data may be loaded from files stored on a disk using the 'Open' option. It is useful to understand that data files in the CSV (comma separated values) file format are compatible with all types of data handling software.
- Using cursors, zoom, assigning axes, altering axes limits.
- Choosing display options: grid, size of points, joined or separate points, hide/show controls, understanding colour coding.
- Define formulae.

**Application skills**

Graphing software can be used to support three main types of learning activity:

- exploring ideas; the learner as an explorer;
• collating and recording; the learner as a receiver;
• presenting and reporting; the learner as a creator.

However, application skills are best developed with the aim of emphasizing the interpretation of data rather than the process of gathering it. Interpretation requires 'engagement' and, although operational skills are a prerequisite, they are insufficient alone. Interpretation depends upon using a series of understandings of global features such as maxima, minima, intervals, relative magnitudes, relative differences, relative gradients, etc.

A progression in interpretation activities is suggested:

• Observing the graph qualitatively. Relating the graph to the events it describes is a basic skill. The graph can be regarded as having a 'story' to tell and pupils might annotate a graph to highlight the main events in the story. There are many features to look for in the graph shape; trends, variations, discontinuities, steepness, and so on. The skilled observer compares these features, considers their relative magnitudes, differences and similarities. It is also important to consider the effect of the axes scales on the graph shape.

• Reading values. Reading off coordinates is the simplest process of obtaining information from the graph; it is much faster and more accurate than manual reading, which can be limited by problems with interpolating, etc. With software, it makes sense to take readings more often, if the information is useful.

• Describing variables. Observations of a qualitative kind can be developed into more precise descriptions by comparing features at two or more positions on the graph. For example, simple calculations from coordinate values such as change, interval, rate of change and gradient can be used to develop quantitative descriptions. It is quite common for pupils to begin describing graphs in terms of their geometrical or numerical properties and they need help in converting these into physical descriptions of the variables involved.

• Relating variables. This involves looking for the connection between changes in one variable with corresponding changes in the other. Cursors which lock on to the graph line help this sort of comparison. A bar display showing the magnitude of values graphically is a further useful aid. As this skill develops, pupils will understand more of the implications of graph shape for describing a relationship and realize that each type of graph shape has distinctive properties.

For example:

*Straight line*: constant rate of change, ratio between corresponding increments in the variables is constant;

*Power curve*: rate of change is variable, for quadratics the gradient changes linearly;

*Exponential*: constant ratio property, rate of change varies in proportion to the vertical variable.

• Predicting. When a relationship between two variables is successfully described, interpolation and extrapolation can be used to predict new data values. Software tools for drawing best fit curves promote confidence in the idea that a relationship transcends the actual points used in plotting the graph. Also, graphs for secondary variables can be predicted; for example velocity–time graphs can be predicted from the shape of distance–time graphs.
Mathematical Modelling. In this progression of interpreting skills, the most refined stage involves describing the relationship between variables as an algebraic expression. The traditional method of doing this is to adjust the variables to produce a straight-line graph, which is the easiest function to recognize and describe algebraically. With software, the same process can be emulated but there are two useful alternative strategies.

Curve matching: Pupils may simulate a function and adjust its parameters until it best matches the shape of the plotted data.

Curve fitting techniques: In a version called ‘Trial Fit’ (Logotron, 1999), the computer calculates the parameters for a best fit function of the pupil’s choice. As pupils gain skill with this technique, they can predict the function which will give the best fit with the data.

A detailed discussion of graph analysis techniques will be found in Rogers (1995).

Case Study 8.1: Rate of reaction

Learning objective:
- to study the effect of concentration on the rate of reaction between sodium thiosulphate and hydrochloric acid.

Added value:
- automatic calculation of data;
- many variables accommodated;
- graphical display.

The data were collected from a light sensor in an experiment in which a small quantity of hydrochloric acid was mixed with a solution of sodium thiosulphate. A torch shone a beam of light through the solution and on to the sensor. As the reaction progressed, a precipitate was formed and the detected light level reduced. Changes in the detected light gave information about the rate of reaction. The experiment was repeated for different concentrations of the solution.

Compared with the traditional ‘disappearing cross’ experiment this data-logging method provides much more information and can prompt much more thinking about the changes occurring (Fig. 8.1). This rich source of data provides a number of alternative methods of measuring and comparing the rates of reaction. Unlike the assumption in the ‘disappearing cross’ method, there is no definite cut-off time which signifies the completion of the reaction. On the graph, this shows as a curved tail. However, the time taken before the precipitate starts forming is clearly visible on the graph and the gradient of the graph can be measured. The cursor tools for measuring changes in light level and time intervals play an important role in obtaining information from the graphs.
Graphing tools

Figure 8.1 Graph for studying the rate of a chemical reaction (Insight 3, courtesy of Logotron)

Table 8.2 Suggested activities for ‘Rate of reaction’ graphs

| Observing | For each of the curves there is a common set of distinctive features; a steady portion, a short ‘blip’, another steady portion, a gentle ‘S’ shape curve followed by a curved tail. Zoom may be used to magnify the vertical scale which emphasizes the changes.
| Sample questions: |
| – Describe the similarities and differences between the set of curves. |
| – What might cause the ‘blip’? |
| – Does the reaction proceed at a steady rate? Explain. |
| – How do you know when the reaction is finished? |

| Reading values | The cursors are used to find values from the graph. Measurements of time interval are made between events represented on the graph.
| Sample questions: |
| – How long does it take for the reaction to start after the solutions are mixed? |
| – How long it takes for the reaction to finish? |

| Describing variables | The analysing tools are used to study changes in the light level and the rate of those changes at different stages of the reaction. |
| Relating variables | Comparing the curves, suggest how their shape is related to the concentration of the solution. |
| Predicting | Predict the shape and position of a curve for a weaker solution. |
Case Study 8.2: Change of State – Freezing and Thawing

Learning objective:
• to study the changes of temperature in bread when placed in a freezer and later removed.

Added value:
• automatic plotting of data;
• graphs are easily rescaled;
• graphs are easily compared.

The data were collected from three temperature sensors in an experiment in which a roll of bread was placed in a freezer for three hours and then removed and allowed to thaw out. One sensor was inserted into the middle of the roll, a second pushed just into the crust and the third placed just outside the roll.

The experiment from which these results were obtained is not viable using conventional methods; reading thermometers inside a freezer is not realistic and it would be far too tedious to collect the quantity of data involved! A graphing program is ideal for examining and analysing this quantity of data (Fig. 8.2). The cursor tools for measuring temperature readings and time intervals play an important role in obtaining information from the graphs.

![Figure 8.2 Graph and 'gradient' tool for studying the freezing and thawing of bread (Insight 3, courtesy of Logotron)](image-url)
Table 8.3 Suggested activities for ‘freezing and thawing’ graphs

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
</tr>
</thead>
</table>
| Observing      | The graph for temperature outside the bread gives some indication of the time taken by the sensors to adapt to their surroundings. The temperatures inside the bread show a certain similarity, but the rates of change of temperature in the crust and in the centre of the roll are distinctive. Zoom may be used to magnify the horizontal scale which allows closer attention to the freezing period or the thawing period. Sample questions:  
  - describe the similarities and differences between the set of curves.  
  - which part of the roll takes longest to cool down? Explain why.  
  - what do you think caused one of the graphs to level out for a while?                                                                                                           |
| Reading values | The cursors are used to find readings from the graph and measurements of time interval between events. Sample questions:  
  - At what temperature does the bread freeze?  
  - How long does it take for the bread to become frozen?                                                                                                                                 |
| Describing variables | The Gradient analysing tool is used to study the rate of change in temperature at different places on the graphs.  
  - Use Gradient to find out the rate of freezing and the rate of thawing in the centre of the roll.  
  - Compare the rates of freezing in the crust and at the centre.                                                                                                                  |
| Predicting     | Predict the shape and position of a curve for a smaller or larger roll.                                                                                                                                                        |

Case Study 8.3: Current and voltage relationships

Learning objective:  
• to study the relationship between current and voltage for a wire resistor and derive information about the resistance and power in the circuit.

Added value:  
• automatic plotting of data;  
• graph axes are easily reassigned;  
• graphs are easily compared;  
• secondary data easily calculated.

A wire resistor was connected in series with an ammeter and variable d.c. power supply. The current in the circuit and the voltage across the resistor were monitored continuously as the power supply was gradually increased to a maximum and then decreased back to zero.
The data for both current and voltage are shown overlaid on top of each other on the graph with time on the horizontal axis (Fig. 8.3).

The plot against time contrasts with the conventional initial plot of current against voltage. The advantage of presenting the graph this way is that both current and voltage can be seen to increase or decrease in unison; the shape of the two graphs is very similar indeed. This reinforces the idea that current and voltage are connected in a simple way. The cursors, which help to read off values, can be used to test out the idea that they increase or decrease in the same ratio. This paves the way for recognizing proportionality, which is shown more explicitly when a graph of current against voltage is plotted. Further data can be calculated from the 'raw' current and voltage values. For example, 'power = current x voltage' and 'resistance = voltage/current'. A graph of resistance against voltage shows that the resistance does not vary with the voltage. A graph of power against voltage shows a rising curve. Using the program to calculate a best fit line reveals this to be a parabola. Again, cursors can be used to study the curve to reveal that when the voltage is doubled, the power is quadrupled, thus indicating the quadratic relationship.
Table 8.4 Suggested activities for 'voltage and current' graphs

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observing</td>
<td><strong>Graph of current and voltage against time:</strong> Both lines rise and fall together. Slight wobbles on the voltage line are also reproduced on the current line. Using the <strong>cursor</strong> and <strong>bar</strong> display reinforces the connection between the voltage and current. <strong>Sample question:</strong> • describe the similarities and differences between the graph lines.</td>
</tr>
<tr>
<td>Reading values</td>
<td><strong>Graph of current and voltage against time:</strong> The <strong>cursors</strong> are used to compare values on the graph. • find out the increase in current when you double the voltage; • find a simple rule for predicting increases in current from voltage increases; • does the resistor obey Ohm's law? Explain.</td>
</tr>
<tr>
<td>Describing variables</td>
<td><strong>Graph of resistance against voltage:</strong> The horizontal line shows that the resistance was constant throughout the experiment.</td>
</tr>
<tr>
<td>Relating variables</td>
<td><strong>Graph of current against voltage:</strong> The straight line indicates that current and voltage are proportional. The <strong>cursors</strong> may be used to verify that the voltage and current increase in the same ratio.</td>
</tr>
<tr>
<td>Predicting</td>
<td><strong>Graph of power against voltage:</strong> The <strong>cursors</strong> are used to measure changes on the graph. • find out what happens to the power when the voltage is doubled.</td>
</tr>
<tr>
<td>Modelling</td>
<td><strong>Graph of power against voltage:</strong> The <strong>Trial fit</strong> (or <strong>Best fit</strong>) facility is used to determine the mathematical formula for the graph.</td>
</tr>
</tbody>
</table>
Chapter 9

Measuring tools

Whatever the mode or purpose of practical work in a school science laboratory, the process of measurement is a common feature of many lessons. For pupils, measurement involves a combination of procedural skills (controlling variables, evaluating reliability, precision and accuracy) and operational skills (manipulation of apparatus, use of measuring instruments, reading scales, tabulation of results), as well as requiring skills of careful observation. With the proliferation of electronic sensors and measuring instruments offering digital readouts, the relevance of some operational skills using traditional instruments such as thermometers and electrical meters has been challenged. The coupling of such instruments with computers to perform data-logging activities has intensified this challenge. The essential effect of data-logging is to automate the process of measurement, the gathering of data and the presentation of the data in table or graph format. The best designs of data-logging software succeed in reducing inauthentic activity, removing tedious repetitive tasks, and generally lowering the operational skill requirement so that there can be a stronger focus on the physical phenomena and procedural aspects of the experiment concerned.

Recommended teaching usage:

- exploring ideas; the learner as an explorer;
- collating and recording; the learner as a receiver;
- presenting and reporting; the learner as a creator.

Features of data-logging

Data-logging begins with sensors. These are usually electrical devices whose function is to detect a physical variable and convert it into an electrical signal. A wide variety of sensors is available (see Table 9.1) but those in most common use are for measuring temperature, light, sound and voltage. The process of measurement, as such, involves connecting the sensor to a data-logger or interface which evaluates the electrical signal electronically, yielding a digitally coded number. The number is either stored inside the data-logger for later retrieval or it is sent directly to a
Table 9.1 Table of sensor types

<table>
<thead>
<tr>
<th>Analogue sensors</th>
<th>Digital sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Pulse detector</td>
</tr>
<tr>
<td>Light intensity</td>
<td>Radiation detector (Geiger-Muller)</td>
</tr>
<tr>
<td>Sound level</td>
<td>Light gate</td>
</tr>
<tr>
<td>Air pressure</td>
<td></td>
</tr>
<tr>
<td>Relative humidity</td>
<td></td>
</tr>
<tr>
<td>Angle of rotation</td>
<td></td>
</tr>
<tr>
<td>Position</td>
<td></td>
</tr>
<tr>
<td>Motion sensor</td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td></td>
</tr>
<tr>
<td>Conductivity</td>
<td></td>
</tr>
<tr>
<td>Magnetic flux density</td>
<td></td>
</tr>
<tr>
<td>Oxygen concentration</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td></td>
</tr>
</tbody>
</table>

computer, usually via the serial port of the computer. Unlike nearly all the other software applications described in this book, data-logging requires additional peripheral equipment to the computer and users need confidence in connecting the extra items (Fig. 9.1), although this is no more complex than connecting a printer, scanner or any of the other peripheral items which are appearing on the domestic market.

Typically, three or more sensors may be plugged into a data-logger, permitting the same number of simultaneous measurements. Normally data-loggers automatically recognize the number and type of sensors connected and automatically calibrate the signals so that the measurements are directly expressed in the natural physical units.
It is characteristic of data-logging experiments that a rapid succession of measurements is available, giving the impression of continuous measurement. In reality the data stream consists of discrete measurements with finite 'inter-sample' time intervals between each measurement. The inter-sample time can be chosen according to the needs of the experiment; under software control it can vary from a few microseconds to several hours. Data-logging programs usually manage the sample rate so that, having chosen the overall duration of an experiment, the total amount of data collected does not become excessive. The collection of up to one thousand items may be regarded as useful for most purposes. In view of the large number of items of data collected, the graph becomes a more convenient tool than the table for presenting the data and it is a prominent feature of data-logging software to offer versatile graphing facilities. Some programs offer further sampling and selecting facilities so that unnecessary items can be discarded, leaving data sets of manageable size.

If the data stream is displayed immediately on the graph, while the experiment is in progress, this mode of logging is said to be in 'real time'. Conversely, if the data-logger stores the data in its own memory, this is described as 'remote logging', reflecting the fact that the logger does not require continuous connection with the computer but can work independently of the computer in a variety of locations, even outdoors. Clearly, after a 'remote logging' session, it is necessary to connect the data-logger to the computer to download the stored data so that it may be viewed and analysed. A further mode of use, variously called 'snapshot', 'single shot' or 'asynchronous' logging, involves recording a series of discrete measurements with irregular inter-sample times. An individual measurement is prompted by pressing a key on the keyboard or a button on the data-logger. Thus individual measurements are under complete control of the user.

Data-loggers can also be programmed to delay the data collection process for a specified period of time or until a certain condition or event is detected by a sensor. Thus the start of logging can be 'triggered' when a sensor reports a certain value or a certain threshold is passed. Under software control, several sets of data may be merged or overlaid on a single graph to aid comparison.

Added value

The advantages of data-logging will be considered by distinguishing between the properties of hardware and software features and the benefits to learning which might flow from each feature. For ease of discussion, the properties have been grouped as shown in Table 9.2.

As with previous examples of software use, our discussion will consider how the properties of data-logging can be exploited in ways which deliver the anticipated benefits in a purposeful learning context. Considering the automatic measuring process first, there are several ways in which the automation makes life 'easier' for pupils, but we need to be sensitive to the value of this to learning, in view of the fact that it implies reduced use of traditional measuring skills. Some teachers might be anxious about this aspect which has long been an integral part of the experience of practical science and such skills are still required for public examinations. We wish to respect place of traditional practice, but question the necessity of its exclusive
Table 9.2 Data-logging properties and potential benefits

<table>
<thead>
<tr>
<th>Properties of data-logging</th>
<th>Potential benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement process is automatic</td>
<td>• low skill level required;</td>
</tr>
<tr>
<td></td>
<td>• time saved;</td>
</tr>
<tr>
<td></td>
<td>• easy to collect more data;</td>
</tr>
<tr>
<td></td>
<td>• frees pupils to make observations.</td>
</tr>
<tr>
<td>Wide range of inter-sample times available (microseconds to hours)</td>
<td>• new contexts for gathering data;</td>
</tr>
<tr>
<td>Remote logging</td>
<td>• less dependence on secondary data</td>
</tr>
<tr>
<td></td>
<td>since pupils can collect their own in a wider range of situations.</td>
</tr>
<tr>
<td>‘Real time’ reporting</td>
<td>• interactive;</td>
</tr>
<tr>
<td></td>
<td>• encourages thinking about data.</td>
</tr>
<tr>
<td>Accuracy of measurements and recording</td>
<td>• reduced errors;</td>
</tr>
<tr>
<td></td>
<td>• better quality information.</td>
</tr>
</tbody>
</table>

application and encourage a balance of use which acknowledges the benefits of the newer methods. For example, for weaker pupils who might normally struggle to make and record measurements systematically, the automation could be liberating, allowing them to obtain their own experimental results without undue uncertainty in the integrity of the data. For all pupils, the ease of data collection can make more time available for other useful tasks. For the time bonus to be a benefit, the choice of tasks needs careful thought by the teacher. Sometimes it is useful to use the time by repeating the experiment several times, under different conditions, allowing several sets of data to be compared with each other. Often, pupils can use the time to make more careful observations of the experiment while logging is in progress (see the reference to ‘real-time’ logging below).

The wide range of available sample rates creates new opportunities for collecting data beyond what can normally be expected in the school context. For example, very fast sample rates allow measurements of transient effects in electrical circuits. Very slow sample rates permit measurements over periods of time which exceed normal class periods; data may be collected over a whole day, evening or weekend. This is especially useful when combined with the ability of a data-logger to store data in its own internal memory. The latter feature makes it possible to function independently of the computer in a so-called ‘remote’ logging mode and provides a valuable aid for field work. The principal effect of this group of features is to expand the number of contexts for performing experiments involving a succession of measurements. The very fast sample rates are useful in physics to measure events which hitherto required storage oscilloscopes, for example, for current surges, capacitor discharges, electromagnetic induction and other transient phenomena. Longer timescale logging is useful in chemistry and biology for slow reactions or changes, for example for some enzyme reactions, photosynthesis, respiration and plant growth. Remote logging lends itself naturally to field work, weather studies, environmental studies and microclimate studies where it is inappropriate or inconvenient to use computers in
close proximity. Remote logging is even useful in the school laboratory for lengthy experiments which do not merit the continuous occupation of a computer. Altogether, there is an expanded range of opportunities for pupils to obtain their own data in situations in which measurements would otherwise be impossible, difficult or tedious, situations where they might have previously relied upon secondary data.

'Real-time' reporting, whereby the measurements are displayed on the computer screen while the experiment is in progress, is a special property of data-logging in respect of the opportunity it offers to completely change the dynamics of the learning process accompanying the experiment. Too often, in traditional measurement activity, pupils are so preoccupied with taking readings and recording them that they become disengaged from the phenomenon of the experiment itself; any thought they might give to the connection between the phenomenon and the recorded numbers or their interpretation becomes quite marginal. The teacher has to work quite hard to prompt this type of thinking. Real-time data logging can change this because the emerging graph on the screen simultaneously reflects physical events in the experiment. Moreover, if pupils deliberately alter a variable in the experiment, the result can be studied immediately. For example, in an experiment to study evaporation in which a small drop of liquid is placed on a temperature probe, the effect of disturbing the probe or assisting the evaporation by blowing across the liquid can be observed on the graph immediately. Experiments like this, which feature intervention and invite a 'predict and test' strategy, provide useful ways of promoting thinking about the phenomenon being studied. As a general principle, pupils should be encouraged to be active observers during experiments involving real-time logging; any surprising or interesting features of the graph should immediately prompt an observation of the apparatus so that events or changes occurring can be immediately associated with the graph. Results which apparently appear to be anomalous should not be disregarded but should prompt further investigation. For example, when temperature probes are placed in liquids, they can be sometimes sensitive to changing convection currents and often sensitive to unwanted movement.

The accuracy of measurement with data-logging techniques is often superior to measurements made by pupils using equivalent conventional instruments. Pupils' measurements have commonly suffered errors in the reading of analogue scales. Computer-based measurements, being a product of an electronic process, are inherently much more reliable than pupils' own measurements, provided the instruments are correctly calibrated and maintained. Also, the security of accurate recording of results is guaranteed with data-logging. Further, the precision of measurements made with some sensors sometimes runs to more decimal places than with the traditional instrument. For example, a temperature probe can usually offer a measurement to a precision of 1/10 of a degree celsius, an order of magnitude better than that of most liquid in glass thermometers. Similarly, light gates offer a precision of timing measurements (microseconds) not normally available with standard school equipment. Overall, therefore, the quality of data available to pupils is greatly improved by the use of computers, a factor which clearly benefits subsequent analysis and interpretation.

We have seen that data-logging offers reliability, quality and variety to the process
of gathering data, but the greater prize often lies in the opportunities in analysing the data. Many benefits also accrue from graphing activities, and the previous chapter on 'Graphing tools' discussed these in more detail. Overall, data-logging and graphing activities facilitate a welcome shift of emphasis from the gathering of data towards its interpretation. This harmonizes well with one of the proclaimed aims of practical work, that of helping pupils to develop their understanding of the substantive science concepts associated with an investigation. To achieve this, pupils must be encouraged to think at the bench; data-logging can create the time to think and graphing software provides tools to assist that thinking.

A cautionary note on accuracy of measurements
In advocating the merits of data-logging we also have to be cautious and acknowledge the limits to the technology. Our experience suggests that many pupils have an implicit trust in the 'goodness' of computer-based measurements and sometimes ascribe accuracy which exceeds the realistic limits of the sensors and software involved. Calibration is no new problem for instrumentation and one only has to connect a class set of ammeters in series or line up a dozen metre rulers to be reminded that there are definite limits to the calibration of simple instruments in common use in schools. Manufacturers of sensors have invested much effort into securing specifications that are compatible with classroom requirements, but the specifications all contain limits which need to be examined to discover aspects such as the reliable working range, linearity and speed of response. For example, a temperature probe, as for a liquid-in-glass thermometer, possesses thermal capacity which slows down its speed of response and inhibits its sensitivity to small temperature changes in particular; most probes are optimized to work within a certain limited temperature range. Similarly, sound sensors have a limited range for reliable values. Simple light sensors are usually nonlinear, giving best results in room lighting but offering poor sensitivity in daylight conditions. pH and dissolved oxygen probes usually require some sort of calibration procedure at each use. The latter sensors often exhibit electrical noise, showing up as small fluctuations in the signal, which tends to obscure small physical changes and should not be confused with the actual phenomenon under observation.

The precision of all data-logging measurements is subject to the process of digitizing the signal from the sensor. The data-logger contains an ADC (analogue to digital converter) circuit for doing this. The effect is to convert the magnitude of the signal into a useful number represented by a digital code. Since digital code cannot express numbers in units smaller than one 'bit', the question which affects the precision of a measurement is 'how large is the physical signal represented by one bit?' In practice this is very small, but it is sufficient to show up as a 'staircase' effect on a graph when high-magnification zoom is used. This is not normally a problem, unless very small values or changes in values require measurement.

Operational skills
These skills concern the manipulation of data-logging hardware and knowledge of the features in the software:
1. connecting sensors and interfaces (including maintenance of batteries);
2. setting up the graph parameters;
3. starting and finishing real time logging;
4. setting up remote logging and subsequently retrieving data;
5. calibration of sensors (optional, depending upon the type of sensor).

For more details, our readers are referred to workbook companions (for example, Frost, 1998).
Beyond the references to operational issues in the preceding paragraphs, a modest amount of further operational knowledge is useful but not essential. Further topics might include: sampling, serial communication, impedance of sensor inputs, types of sensor (analogue and digital), logarithmic and linear sensors, digital and analogue measurements. For more details, we refer our readers to manufacturers' instruction manuals and computer texts.

Application skills
As indicated in earlier chapters, a prerequisite for this section is that pupils have achieved a suitable threshold of operational skill embracing the topics outlined in the previous section. We now wish to focus on putting those skills to use to the benefit of learning. Our discussion of the skills of application for data-logging software will exemplify three main types of learning activity:

• exploring ideas; the learner as an explorer;
• collating and recording; the learner as a receiver;
• presenting and reporting; the learner as a creator.

We shall begin by proposing two main principles when selecting and designing activities:

1. To be clear about the learning objectives of the activity and ensure that they match the teacher's intentions.
2. To exploit the full potential of the data-logging approach.

These principles embody our wish to promote 'appropriate' rather than 'indiscriminate' use of ICT. In the case of practical science there are many temptations to use data-logging as a substitute for well proven conventional methods without a valid rationale. On the other hand, ignoring a data-logging opportunity can be a valuable opportunity lost. For all lessons involving data-logging, there are special management issues related to the availability, distribution and use of equipment which need to be addressed. A later section will deal with some of these issues but at this point it is important to acknowledge that classroom logistics are bound to have a bearing on judgements of appropriate use. Also, since measurement is implicitly a practical activity, an important aspect of pupils' application skill resides in their ability to manipulate apparatus and design experimental procedures and fair tests. Pupils need a sufficiently secure foundation in these skills before data-logging activity can flourish.
Examples which identify learning objectives will be considered in the case studies that follow. To consider the full potential of data-logging, we need to refer back to the section on 'added-value'.

• **Using the time bonus.** In previous discussion we saw that teachers need to make judgements about the most effective ways of using the time bonus. For pupils this means developing a culture of questioning and observation during experiments so that the time bonus is not wasted. Pupils might also be encouraged to think of useful repetitions of an experiment, to confirm trends in the results or to explore the effect of changing variables. It is useful to set such extension activities in an exploratory mode.

• **New experiment opportunities.** The ability to record measurements very rapidly or very slowly are special aspects of data-logging which are often very difficult to replicate by conventional methods. In both aspects the graph plays a major part in performing useful tasks on the data so pupils need to develop many of the application skills described in the previous chapter on 'Graphing tools'. There are also a number of intrinsic properties of data-logging which contribute unique measurement opportunities: the rapid collection of data simulates continuous measurement; several sensors in use simultaneously yield simultaneous sets of data. In contrast, experiments which only require a small number of readings are poor candidates for data-logging.

• **Real-time logging.** As suggested previously, during experiments involving real-time logging, pupils should be encouraged to be active observers. The short time cycle between testing an idea, observing effects, obtaining a measurement and seeing results on a graph is a great encouragement to developing investigative skills: informal experiments and trial runs can inform planning; automatic measurements create plentiful evidence; the graph supports the evaluation of evidence. Real-time logging can accelerate these processes and encourage exploratory learning. Although it is our belief that data-logging has most to offer pupils working in an investigative mode, it can also be useful as a tool for teacher-demonstration. As with many non-computer demonstrations, the teacher can orchestrate class questions to prompt a spirit of inquiry; however, real-time logging and graphing can accelerate the discussion process.

• **Measurement quality.** The use of electrical sensors frequently offers impressive precision, bearing in mind the cautionary note above. For example, light gates facilitate discrete time measurements of the order of a few microseconds, which is very useful for monitoring motion. The consequent number of decimal places, however, needs to be used judiciously, especially when experimental conditions yield a spread of values in repeated measurements. Care must also be taken in limiting the number of decimal places when using the results in calculations involving other measurements of poorer precision. A common example is the calculation of velocity using distance measurements which are usually only accurate to the nearest millimetre. Another aspect of measurement quality is the excellent sensitivity available in some sensors. For example, certain thermocouple probes can measure tiny changes of temperature and many light sensors are far more sensitive than the human eye in terms of intensity and spectral response. Teaching approaches should attempt to
encourage the learner as an ‘alert’ receiver by cultivating an appreciation of precision and sensitivity.

- **Analysis opportunities.** Since the graph is a major tool for reporting measurements obtained through data-logging methods, there are further relevant application skills as discussed in Chapter 8. Such activity is ideal for supporting an exploratory mode of learning. The case studies which follow, together with those in Chapter 8 give vision of the rich opportunities for exploring and learning from collected data.

**Case Study 9.1: Motion experiments with light gates**

*Learning objective:*
- to identify the connection between the velocity of a trolley and the distance it travels down a runway.

*Added value:*
- real time reporting;
- automatic tabulation of results;
- automatic calculation of velocities;
- prompt graph display;
- analysis of graph.

This example describes an investigation of the motion of a trolley on a sloping runway. The aim is to identify the connection between the velocity of the trolley and the distance it travels down the runway. The example is one illustration of a series of experiments which may be conducted with a light gate sensor for studying the motion of wheeled vehicles. The light gate is used to detect the movement of the trolley; by attaching a narrow card to the trolley and allowing it to pass through the beam of the light gate; the time for the interruption of the beam is measured by a computer. The data-logging program calculates the speed of the trolley from the interruption time and the length of the card.

To help pupils get used to the measurement process, it is useful to start off with a few informal experiments, gently pushing the trolley through the light gate (Fig. 9.2) and noticing how the data-logging program calculates the velocity of the trolley automatically and inserts the results into a table on the screen. For the calculation to be automatic, pupils first need to type the length of the card into the program.

![Figure 9.2 Use of light gate for detecting movement](image-url)
To begin the investigation, the runway is propped up to give a gentle slope. The trolley is released from the top and rolls down the slope through the light gate. The experiment is repeated many times with the light gate located at different positions down the slope. For each position, the distance from the card to the light gate is measured using a metre ruler and typed into the program. The program generates a table and plots a graph as shown in Figure 9.3.

![Figure 9.3 Table and graph of data recording the motion of a trolley (Insight 3, courtesy of Logotron)](image)

This is a good example of real-time reporting, since, as results accumulate, the number of rows in the table grows and more points appear on the graph automatically. Pupils do not need to be concerned about calculating the values of velocity; they can focus their attention on the relationship between the magnitude of velocity and the distance from the light gate. The data-logging program was deliberately configured to emphasize this relationship by presenting the calculated velocities rather than the interruption time measurements. Teachers may wish to reflect on this design choice: an alternative configuration would present the interruption times, requiring pupils to add a further column to calculate the velocities. The additional process, although reinforcing the method by which velocities are calculated, is a distraction from the main aim of the experiment. Since the distances are measured by pupils with a ruler, this experiment represents a mixture of data-logging and manual measurement.
Teachers will recognize the investigative spirit of this example; the declared aim is to look for a connection between distance and velocity. As data accumulates, pupils should be encouraged to make observations to gain an informal feel for this connection. They might be encouraged to predict the velocity when, say, the distance is doubled or trebled. It is always a good idea to repeat measurements several times to gain a sense of the reliability of the evidence. This sort of interactive approach is also valuable for spotting anomalous results, when they occur. When a complete set of data has been collected, a more precise exploration of the relationship can be made by evaluating a curve of best fit on the graph: the program offers a formula for the curve describing the relationship. In the Trial fit version of curve fitting (Logotron, 1999), pupils are able to experiment with trying out different general formulae to see for themselves which offers the best fit to the data. A further exploration can be made by using the program to calculate a new column of data for the velocity squared and plotting this against distance. The resulting straight-line graph confirms the relationship.

The experiment may be repeated for different slopes and different surfaces on the runway (e.g. place some thin carpet on the surface) and comparisons made.

### Sample questions:

Informal experiments pushing the trolley through the light gate:
- How is the velocity of the trolley related to the strength of your push?
- Does the direction of motion affect the velocity?

When you allow the trolley to roll down the slope:
- What factors are likely to affect the velocity of the trolley?
- What are the main features of the graph of velocity against distance?
- What does the graph tell you about the velocity of the trolley as it travels further down the slope?

### Case Study 9.2: Evaporation of liquids

**Learning objectives:**
- to observe the cooling effect when a liquid evaporates;
- to identify the factors which affect the rate of evaporation for different liquids.

**Added value:**
- real time graphing;
- simultaneous measurements;
- immediate link between experiment and graph;
- analysis of graph;
- opportunities for informal experiments and discussion.

Temperature probes are very useful for conducting a large variety of simple experiments involving heating and cooling. Quite cheap probes can offer excellent sensitivity and accuracy well suited to real-time experiments. In this example, the cooling resulting from the evaporation of a liquid is studied. The basic experiment
involves one, two or three probes connected to the data-logger with the temperature readings reported on a real-time graph on the screen. Many informal variations can be made on the basic theme. For example, dipping one or two probes into a bottle containing a volatile liquid such as methylated spirit:

1. Predict, then observe the change when a probe is dipped into the liquid. No change, usually!
2. Speculate about the change of temperature when the probe is removed from the liquid.
3. Notice the duration of the cooling effect. Speculate about factors affecting this.
4. Remove from the liquid two probes simultaneously, shaking one of them vigorously.
5. Notice how the cooling effect depends upon the speed of shaking.
6. Blow across a moistened probe or use a fan to create a draught.

The spirit of simple activities like these is to pose many questions and exploit the immediacy of the graph on the screen to gain answers, giving a truly interactive experience. Real-time logging is a very useful tool for supporting an interplay between thinking and hands-on activity.

In a more formal experimental arrangement, three temperature probes were fixed to a clampstand. The tip of each probe was wrapped with a small piece of tissue paper which was then soaked with a few drops of liquid. A different liquid was used for each probe: water, methylated spirit and ether. During the experiment it became quite clear that the different liquids cool at different rates and reached different minimum temperatures. The context for appreciating these differences is usefully set by the previous informal experiments. Figure 9.4 shows a typical graph of results collected over several minutes.

![Figure 9.4 Graph recording evaporation of liquids (Insight 3, courtesy of Logotron)](image-url)
After the experiment, the real-time experience can be re-lived to a certain extent using the graph cursors and bar display: As the $X$ cursor is dragged slowly across the screen, the bars grow and shrink in the same manner as the changes of the temperature values during the experiment, thus creating an 'action replay' effect.

Other graphing tools allow pupils to measure and compare the rate of cooling with the rate of recovery of the temperatures and the average temperatures overall for each liquid. Comparisons can be made with further similar experiments conducted under different conditions such as in an insulated draught-proof box or with the use of an electric fan.

The benefit of data-logging in this experiment comes from making immediate observations of the data, asking questions about it, looking for links with other information, making comparisons, making predictions, looking for trends and so on. In short, the benefits depend upon the quality of the thinking about the data. Teachers are skilled in prompting pupils to think. Here is an important context for exercising this skill. This has been highlighted in Barton's studies of pupils' interpretation of graphs presented with software (Barton, 1997).

Case Study 9.3: Microclimate and weather studies

Learning objective:
• to study the variation of temperature in a room over a period of time.

Added value:
• remote logging;
• simultaneous measurements;
• accumulation of data over several days;
• analysis of graph.

There is a group of medium- to long-term experiments which would be generally inconvenient without data-logging technology. Their theme is that of investigating the climate in a small or limited locality, an idea that can be applied to a wide variety of situations both indoors and outdoors. The main types of measurement are temperature, light, humidity, air pressure and perhaps sound. Examples of outdoor experiments include investigations in flower beds, above, below and at the surface of the soil; comparing conditions inside and outside shrubs or bushes; comparing woodland with fields. Indoors, pupils can investigate temperatures in a room, on a window sill, inside a fridge, inside an animal cage or an aquarium. In most cases the focus of study is on changes of the observed quantities with respect to time; the effects due to the daily cycle of the sun or to changes in the macroclimate or other ambient phenomena are all reported in the collected data.

The common factor through all these experiments is the systematic collection of data over long periods of hours or days. The data are stored within the data-logger and the opportunities for viewing the data actually during the experiment are very limited. Normally the data are downloaded into the computer after the experiment and only then can it be studied. Unlike the case of real-time logging, the engagement between pupils and the experiment whilst in progress is minimal. The nature of
remote logging experiments is that they form a background process whilst pupils' attention is engaged in other activities.

The example described here involved a series of temperature measurements in a bedroom. Two temperature probes were positioned, one near the ceiling, the other near the floor, and the data-logger was set to run for ten days. Both probes were shielded from direct sunlight so that the measurements would indicate air temperatures only. During such an investigation there are very few worthwhile physical observations for pupils to make. The main teaching activities occur beforehand at the planning stage and afterwards when the collected data can be analysed. In the spirit of an investigation, pupils should be full participants in the planning of the investigation and discuss the range of variables involved and how fair tests might be designed. Teachers will need to consider the most effective way of prompting such discussion, through whole class discussion, group discussion, a worksheet or an on-screen tutorial.

Examples of issues for the planning stage:
- What is the orientation of the window (north, south, east or west)?
- What might be the effect of the size of window?
- Will the window be open or closed?
- Will the curtains be drawn or open?
- What is a suitable duration for the experiment, to learn something useful?

At the conclusion of data collection and having downloaded the data from the data-logger to the computer, the main learning activity can begin. This is largely dependent on analysing the data presented as a graph and the application skills relevant to using graphing software are called upon. Again, teachers need to think about the most effective way of structuring and prompting pupils' exploration of the data. Some suggestions for questions are offered below. The data presented here is slightly unusual in that it was collected during a remarkable heat wave; the decline of the heat wave conditions is captured in the latter half of data collection. Of special interest are the extremes of temperature, the daily cycle of changes and the consistency of the difference between ceiling and floor temperatures during the first five days followed by a different pattern during the latter five days (Fig. 9.5).

Management issues
The discontinuous nature of this sort of practical work requires careful management, mainly focusing on getting the activity launched and later analysing the collected data. Remote logging often fits in well with group project work or whole investigations which normally demand a more flexible style of lesson management to cope with a variety of different needs. Briefing worksheets may be needed for supporting pupils' planning and giving basic instructions for setting up the hardware and software. There need to be satisfactory arrangements for leaving the apparatus securely outside the normal lesson times. The battery life of data-loggers needs to be assured; in general, manufacturers' claims need to be questioned. For long-term experiments it is wise to use mains adapters where possible, or car batteries. For
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Figure 9.5 Graph recording the variation of room temperatures (Insight 3, courtesy of Logotron)

Sample tasks and questions:
• explain the distinctive cycles of change during the first five days;
• find out the time interval for each cycle. Does this confirm your explanation?
• take measurements of the peaks and troughs;
• calculate the swings in temperature during the first five days;
• find the average temperature for the first five days and compare this with the average temperature for the second five days;
• compare the two sets of data (from the two probes), describing the similarities and differences;
• plot a graph of the difference between the two sets of temperatures. What useful information can be taken from this graph?
• suggest an explanation for ceiling temperatures being generally different from those near the floor;
• suggest some experiments you might try out in the laboratory to test your explanation.
outdoor experiments, sensors and equipment need protection from rain and possibly theft. The scheduling of computer use is mainly concerned with downloading and analysing the data after the experiment.

Case Study 9.4: Investigating motion using a ‘Motion Sensor’

Learning objectives:
• to obtain distance–time and velocity–time graphs for people walking around;
• to relate the features of the graphs to the motion of the people.

Added value:
• immediate display of graph in ‘real time’ during data collection;
• interaction between thinking about the graph and feeling the motion;
• analysis of graph.

The ‘motion sensor’ emits pulses of ultrasound and detects their echoes from nearby objects. When connected to a computer it provides information about the distance of the object causing the echo. It can be used to detect the motion of pupils walking, or of wheeled vehicles moving backwards and forwards in front of the sensor. The fact that pupils can use the sensor to detect the motion of their own bodies provides a unique experience in the repertoire of data-logging activities; the interaction between the pupils’ movement and their interpretation of the resulting graph shape provide much intuitive learning about distance–time graphs. It is ideal for activities in small groups. In each case, the sensor is set up by the side of the computer screen facing the users in front of the screen.

Activity 1. Predicting and testing
The screen is first covered over with a piece of card. The computer is set logging and one pupil performs a simple sequence of movements in front of the sensor. Other pupils in the group then predict and sketch on a piece of paper the shape of the graph they expect. The predictions can then be checked by removing the cover.

Activity 2. Matching graphs
One pupil performs a simple movement in front of the screen to create a graph. A second pupil is then challenged to imitate the movement so that a second graph overlays precisely on the first. Alternatively, a pre-defined graph is displayed on the screen and a pupil attempts to move in a way that produces exactly the same shape graph, overlaid on the first (Figure 9.6). This exercise is excellent for provoking much thinking and discussion about the match or mismatch between the two graphs. Best results are obtained if, before starting, pupils carefully observe the graph to be imitated, noting the coordinates of salient features, and planning their movement accordingly.

Activity 3. Predicting velocity–time graphs
The computer readily converts a distance–time graph into a velocity–time graph and both can be viewed on the screen simultaneously. Comparing the graphs, or predicting the shape of one from the other provides a valuable discussion activity.
The sensor can also be used to yield the quantitative measurements employed in 'conventional' experiments with dynamics trolleys to investigate the laws of motion. Such uses are well rehearsed and need no further explanation here. Instead, the informal experiments described here illustrate a practical expression of a common theme in this book, that of giving pupils an active role in designing and shaping their work. Experience with the motion sensor confirms how creative and motivated pupils can be when encouraged to work in an exploratory and investigative mode.

Incorporating data-logging into lessons

The four case studies have illustrated how data-logging can take a variety of different forms. A further dimension is added to this variety when we consider how the data-logging activity is managed within the lesson. It is possible to identify several distinctive modes of use according to the manner of organization:

**Demonstration**  Teacher demonstrates an experiment to the whole class. This requires a large screen or data projector.  
*Example:* Observe oxygen in a bell jar with a candle.

**Subdivided class**  Half the class performs a data-logging experiment whilst the other half performs the conventional equivalent. The two methods are compared in class discussion.
Example: Rate of reaction of sodium thiosulphate and an acid.

Circus
The data-logging experiment is one of several activities which are performed on a rotational basis. All pupils may perform all the experiments, but not all at the same time.
Example: Use of the 'motion sensor' to study motion.

Parallel experiment
The class performs a conventional experiment whilst the teacher or one group performs a data-logging version of the same experiment.
Example: Cooling curves for stearic acid.

Dip in and out
A quick experiment for pupils to do, but peripheral to the main lesson.
Example: Observe the constant period of a pendulum.

Revision/extension
A data-logging experiment is used to give a fresh approach to a previous experiment or to provide reinforcement.
Example: Current–voltage curves for electrical components.

Whole class
When sufficient lap-top or palm-top computers are available, a whole class can perform the same experiment. (Desk-top computers generally occupy too much bench space.)
Example: Cooling curves for investigating thermal insulation.

Whole class
The whole class goes to the computer room to analyse previously collected data.
Example: Analyse data collected on a field study.

(We are grateful to Dr Roy Barton who originated this format for our discussion of these ideas.)
Part 3

Afterword

The preceding parts of this book set out a view of the potential contribution that ICT can make to teaching and learning science. The discussion has retained a high profile for the learner, but has also emphasized the role of the teacher, as a designer and manager of pupils' experience in the classroom. For this reason we have sought to address what teachers need to understand in their planning and do in their lessons in order that ICT can make an effective contribution.

This final chapter invites the reader to consider how they might respond to the issues raised in their own professional practice. To this end the discussion focuses on the needs of learners and the enduring importance of the teacher's role in planning and managing science lessons when using ICT.
Chapter 10

Moving on with ICT in science teaching

A primary goal of science education is to contribute to the intellectual development of learners through the acquisition and application of scientific knowledge, skills and understanding. We have set out a view of the potential contribution that ICT can make to this endeavour. The discussion has retained a high profile for the learner, but has also emphasized the role of the teacher, as a gatekeeper of pupils’ experience in the classroom. Consequently, much of the discussion has addressed what teachers need to understand in their planning and do in their lessons in order that ICT can make an effective contribution. This final chapter revisits the dominant themes of earlier discussions in order to help readers consider how they might respond to the issues raised about their own professional practice.

Focusing on the needs of learners

In previous chapters we have described some of the skills, understanding and knowledge of software required to help teachers make the most of what ICT has to offer science learners. The ultimate beneficiaries in this endeavour must be pupils themselves, and it is our hope that the insights we offer will spur our readers into developing their own approaches to teaching science with ICT. Although the planning and delivery of science curricula to pupils are essentially teaching activities, to be successful they must retain a strong link with the needs of the learners who are the recipients of their teachers’ efforts. Teachers have various roles in education, and chief amongst these is the role as a designer of pupils’ learning experiences. It seems futile to develop teaching episodes without that planning being informed by what we know about learners and learning. It has not been our purpose in this book to offer an extensive discussion on learning, but readers can be usefully guided to some of the salient features of effective learning by the Learner-Centred Psychological Principles recently identified by the American Psychological Association (APA, 1997). These principles identify the importance to learning of:

- construction of meaning from information and experience;
- directed learning goals;
- linking new with existing knowledge;
• using a range of thinking strategies;
• critical and strategic thinking;
• acknowledging the influence of contexts of learning;
• motivation to learn and willingness to expend effort;
• developmental readiness;
• social interaction;
• learning preference;
• acknowledging diversity;
• the role of assessment.

Readers will want to reflect on the extent to which the ICT tools we have discussed in this book can be used to design learning episodes that build on these principles.

Making appropriate use of software – the match between fitness and purpose

In order to develop a rationale for using ICT, it is necessary to understand the links between learning purposes and the choice and design of an activity. The selection of a particular activity or teaching approach must be driven by the learning purpose, so clarity of purpose is of primary importance to inform lesson planning. The earlier discussion of software types offered a view of the possible teaching uses and the learning roles that can be supported by ICT. In our view, the success of science teaching with ICT is dependent on the quality of the match between learning purpose and the selected teaching approach. To this end, teachers need to have an understanding of the possible value added to activities by ICT and to be able to identify the benefits of the chosen method compared with alternative 'non-ICT' approaches.

It is important to appreciate that a consideration of the benefits of ICT is not as straightforward as might first appear. Although ICT can have some obvious advantages, factors other than the choice of software itself can be influential in securing the benefits for pupils. In particular, the mode of classroom application of ICT profoundly shapes the pupils' experience. For this reason we have distinguished between 'properties' of software and the 'potential learning benefits' which might come from them.

Having identified a learning purpose, teachers need to think about what software can do and what it might contribute to the intended purpose. Then, a particular software instrument can be selected because it possesses certain properties and offers particular benefits suited to that learning purpose. As teachers become more experienced in the use of particular pieces of software, so appreciation of the value they can add to learning activities grows. There is a real sense in which increasing familiarity with the use of ICT can foster the development of new activities. Over time, this can lead to insightful new uses for software, that, in turn, leads teachers to develop 'new' learning objectives. Rewards of this kind are won through a maturity of experience and reflection on using ICT in science teaching.

Investigative work requires the application of skills in practical contexts. As we saw in Chapter 3, we can think of application of investigative skills involving both their execution with technical proficiency, and their use with understanding. This understanding relates to the knowledge and thought that underpins the selective exercise of skills in particular (and appropriate) investigative contexts. This so-called
procedural understanding (Gott and Duggan, 1995) embraces the concepts of experimental variables (their identification and manipulation), fair testing, frequency of measurement, reliability in data, interpretation of data, etc. An important effect of ICT is to shift the balance in the exercise of these investigative skills. Computers can perform some of the technical skills for example, measurement, data collation and graphing; this can unfetter the learner to focus more on procedural and interpretative matters. Despite this benefit, we cannot deny that introducing large amounts of technology into practical science investigations adds to the level of skill demand. There is a danger that increasing the operational demands of an activity obscures the science learning purpose. For this reason teachers need to be vigilant in ensuring a suitable match between the purpose of the activity and the experience of the pupils using ICT.

The additional operational skills requirement for ICT-based investigative work presents teachers with a challenge. Clearly, pupils will need training in new skills and the investment in this will have to be considered against the relative usefulness of ICT-based approaches compared with more 'conventional' ones. We see this as a critical judgement of fitness for science purpose, a judgement that teachers must make in their own professional contexts, but one which, we hope, gives due recognition to the benefits of ICT approaches described in foregoing chapters. We note here that critical selection of ICT activities is a theme both in the UK Training Standards for newly qualified teachers (DfEE, 1998) and in recent UK government funded ICT training initiatives (TTA, 1998).

Interactivity and the needs of learners

Pupils should be the beneficiaries of the potential of ICT and interactivity is an important means of serving the needs of learners. It is worthwhile dwelling on what we mean by interactivity in this discussion, because we can view it superficially or at a more useful, deeper level. Securing the benefits of ICT will crucially involve the learner in interacting with software in some way. At face value, some software can appear to be very interactive. It can engage users in its operation and in navigation of the interface using the mouse, and this can encourage what might be called 'click-happy' behaviour. The problem is that this quality of 'clickiness' can lead to haphazard and unproductive use of software.

In other circumstances, interactivity can be seen at a deeper level; here it can be purposeful, challenging and encourage thoughtful reflection in pupils. Carefully structured activities using well-designed software can demand high levels of intellectual engagement by the pupil. Interactivity in this mode promises understanding but it cannot be secured without effort and struggle on the part of the learner. This has implications for teachers both at the lesson planning stage, where strategies to engage the learner must be considered and also in terms of useful teacher behaviours whilst activities are in progress.

Teaching science with ICT – the teacher's role

In our consideration of the skills required by pupils and teachers working with ICT, we have distinguished between operational skills and application skills. Often, the
development of teachers’ own ICT skills will precede those of the pupils and teachers will have an important role in passing these skills on. This may be less important for some aspects of operational skill where pupils’ familiarity or experience with a particular piece of software may make them the ‘expert’. Nevertheless, a dominant feature of many in-service ICT training programmes in practice has been the need to raise the level of teachers’ operational skills (DfEE, 1998; TTA, 1998). However, it is application skills that need to be to the fore both in lesson planning and in the translation of lesson plans into actions in the classroom; this leads us to a consideration of teachers’ roles in these two general respects.

Planning lessons
We have already discussed the importance to planning of defining clear objectives. Often, the content objectives will be specified in curriculum statements or syllabus requirements, but these will need to broken down into manageable outcomes for individual lessons. In addition, objectives designed to build pupils’ repertoire of operational skills will figure in planning, but as we have seen, it is important that these should not become the dominant focus of activity.

A good understanding and appreciation of the potential of software, its properties and the added value it offers, should help teachers achieve a suitable balance of operational and application objectives. These objectives need to be explicit and they will need to be well matched to the pupils’ age and ability. Where pupils need to develop new operational skills, for example knowledge of new software tools, or application skills, for example investigative strategies, they should be developed within a suitable science context.

Pupils’ experience of science should be as authentic as possible and so the choice of task context should pose real problems or issues for investigation and encourage scientific ways of working. In this spirit, planning should encourage enquiry and build in roles for pupils to speculate on possible findings; where appropriate they can also make predictions, which can be tested.

ICT lends itself to enquiry-based approaches because it offers a range of tools that can be used to find answers to questions. Often, this kind of atmosphere is best achieved through collaborative group work and so teachers will want to consider at the planning stage how best to organize the pupils. This can mean planning for pupils to take more control of decision making during the course of an enquiry. A willingness to act more as facilitators of pupil activity will help teachers to ‘lead from the back’ rather than operating in a more didactic manner. This stance requires a degree of self-confidence and experience on the part of the teacher, as well as good knowledge of the pupils. We should acknowledge the fact that pupils need to learn how to work in this way and that it will take time for them to gain experience in this. It is certainly unlikely to be achieved in a single lesson! Nevertheless, many of the benefits for pupils working with ICT derive from the opportunities they offer for interactivity between individuals or small groups. For this reason, modes of classroom activity involving ICT need to shift towards greater autonomy for pupils rather than being overly directed by the teacher. In our view this does not diminish the role of the teacher but recasts it for the new context created by use of ICT. This leads us to consider the second aspect of the teachers’ role – that of managing lessons in action.
Managing lessons
When activities are presented to the pupils in lessons, the style of presentation becomes very important. We have argued that teachers need to adopt a questioning approach because this serves to raise interest and adds to the authenticity of the pupils' experience. If the teachers' approach models curiosity and fosters a spirit of enquiry in pupils by encouraging speculation, this will help to bring the science questions to the foreground and create a productive classroom climate in which ICT tools can be useful.

During ICT-based activity, the teacher's role of knowledge provider is likely to be diminished by ICT. In contrast, the roles of enabler, challenger, adviser and respondent to pupils can take on much greater importance. It is hard to envisage machines taking on these roles with great success when compared with the skills of experienced teachers interacting with pupils, and dealing with the host of issues and questions that can arise in classrooms. In our view, teacher interventions in pupil activity are of high value in even the most technology-rich classrooms, for several reasons. Teachers can use questions to tease out pupils' ideas and help to make them explicit. Probing questions can challenge understanding and promote a struggle with ideas to encourage learning. In the process, teachers can model scientifically acceptable language for pupils; this helps pupils to learn to 'talk science'. These are examples of effective teaching skills in any problem-solving context. But they can be overlooked in ICT lessons, especially when operational skills become the focus of teacher attention. It is to be hoped that continued improvements in technology will further reduce the burden on teachers to resolve technical problems, and that operational skills will become well embedded in pupils experience over time. Despite this ambition, teacher interventions provide opportunities to help pupils in several other respects. Timely interventions can support pupils in:

- learning to notice – focusing attention of what is salient and significant in data;
- reminding them about what they already know and can do, and building on this in new contexts;
- highlighting special features of software and suggest further applications of these;
- prompting them to make links between observations and their knowledge or experience;
- reducing 'early closure' in dialogue by prompting discussion;
- encouraging prediction and comparison with reality;
- keeping science questions to the fore through interpretation of data and linking with science knowledge.

Assessing pupils' progress and evaluating the usefulness of ICT activities
Teacher interventions can provide useful opportunities for formative and diagnostic assessment of pupils' progress during ICT activities. But how does ICT change what is assessed and how it is assessed?

In our discussion, the primary object of assessment should be pupils' scientific skills, knowledge and understanding rather than their ICT capability. The use of ICT 'tools' clearly has an impact on pupils' science skills and will change a teacher's
expectations of pupil achievements. For example, proofing tools used to check spelling and grammar in a word processed document, or graphing software used to plot a line graph of experimental data are two instances where use of software makes assessment of the underlying skills redundant. Clearly, if the teachers' purpose is to assess pupils in these skills, the use of software is inappropriate. Tackling this issue requires us to recognize that software tools serve some purposes well and others less so. This is a further argument for teachers having a clear purpose in mind when using software in their lessons.

Assessment of scientific knowledge and understanding in ICT contexts requires teachers to be able to see beyond surface features of pupils' work, such as quality of presentation or the extent of information gathered from an electronic resource. Both of these qualities can be significantly enhanced using ICT but this does not necessarily indicate improved performance in science on the part of the pupil. A related argument can be made regarding the originality of pupils' written work using ICT, where the potential for plagiarism of CD-ROM and internet sources is high. In each of these examples, assessment needs to consider the ways in which pupils make use of information for a science purpose and we have explored this theme extensively throughout this book by reference to application skills.

A strong case has been made for the benefits of collaborative computer-based activity, but group work poses problems for teachers in making assessments. The problem is how teachers can identify the contributions in the joint endeavour of individual group members. This difficulty is not exclusive to ICT activities, but teacher interventions during tasks can provide ephemeral evidence of an individual pupil's progress in a group task and this raises the importance of such interventions still further. Teachers need to engage pupils in dialogue about their work and plan to make observations of pupils' activity in order to provide evidence for assessment purposes.

Finally, we should consider how the effectiveness of using ICT to achieve science objectives could be evaluated. This issue has been addressed in terms of the 'added value' that various ICT tools can offer to learning objectives, and through a discussion of the balance between operational and application skills in an activity. Taken together, these themes serve to provide criteria against which the usefulness of an ICT approach can be judged. Although learning objectives usually emerge from curriculum statements, it is to be hoped that teachers' vision of the worthiness of software and its contribution to securing learning objectives will inform the future process of defining them.

Operational and application skills for the future

Whatever the likely future developments in software, our view is that effective teaching practices with ICT will remain of high importance. Teacher's professional knowledge of ICT developments will move forward with technological advances. This will involve building confidence in operational skills, acquiring knowledge of software and the exchange of ideas with other practitioners.

The range of operational and application skills that have been described in this book are listed in Tables 10.1 and 10.2 respectively. If we consider operational skills together, many of these are generic skills in which pupils will gain experience in a
variety of curriculum subjects. Others are more specialized, and in the case of graphing and data-logging software, science is especially well placed to support use of these skills.

Table 10.1 Operational skills for ICT in science education

- keyboard and typing skills;
- launching a program;
- windows skills: mouse, clicking, scrolling, dragging, highlighting;
- minimise, maximise, undo, redo;
- managing folders and files;
- file operations: open, save and print;
- file formats (text, graphics etc.);
- editing: cut, copy, paste;
- printing;
- font selection and formatting, styles;
- layout and tabs for positioning text and graphics;
- proofing tools: spelling checker, grammar checker, dictionary;
- inserting tables and charts.

- defining formulae;
- sorting data;
- using templates;
- drawing lines and shapes;
- importing text and graphics from other sources;
- adding hyperlinks.

- using cursors, zoom, assigning axes, altering axes limits;
- choosing display options: grid, points, lines, hide/show controls, use of colour coding;
- defining formulae.

- connecting sensors and interfaces (including batteries maintenance);
- choosing logging parameters; duration, sample rate;
- starting and finishing real-time logging;
- setting up remote logging and subsequently retrieving data;
- calibration of sensors (optional, depending upon the type of sensor).

Application skills can be viewed as comprising skills for both teachers and pupils, although the particular emphasis of each skill will be influenced by the context of its use. For example, the use of the time bonus, questions of differentiation and curriculum relevance can be considered as essentially concerning teachers in lesson planning. The majority of application skills concern mode of use and some of these skills have equivalents in non-ICT teaching approaches. Teachers can take some reassurance that many of their professional skills have relevance in ICT settings. ICT has many good things to offer teachers and its use augments the teachers' role, particularly in relation to classroom intervention strategies.

This book has offered a number of exemplary case studies which give vision of what can be achieved with ICT in science and awareness of the skills involved. The lists of skills may appear daunting for some, but it is not necessary for science teachers to be immediately accomplished in all aspects of ICT use. As a general
approach to planning, it is better to include in a scheme of work, a few well-rehearsed ICT activities, for which a clear rationale has been developed than to use ICT at every opportunity regardless of the value it brings to the lesson. Uncritical use of ICT not only risks wasting time but also offers a poor experience of its use, devaluing a resource of real learning potential.

Table 10.2 Application skills for ICT tools in science education

<table>
<thead>
<tr>
<th>Information systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>• assessing suitability of content;</td>
</tr>
<tr>
<td>• selecting relevant information for a science purpose;</td>
</tr>
<tr>
<td>• evaluating appropriate age level (teacher skill);</td>
</tr>
<tr>
<td>• differentiation (teacher skill);</td>
</tr>
<tr>
<td>• evaluation of reliability and validity, balance and objectivity of information;</td>
</tr>
<tr>
<td>• awareness of linguistic style;</td>
</tr>
<tr>
<td>• focused searching using search engines and directories; database queries;</td>
</tr>
<tr>
<td>• remodelling information – not just copying.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Publishing tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>• identifying writing purpose;</td>
</tr>
<tr>
<td>• identifying audience;</td>
</tr>
<tr>
<td>• selecting a suitable genre;</td>
</tr>
<tr>
<td>• structuring text;</td>
</tr>
<tr>
<td>• remodelling text (redrafting).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Visual aids</th>
</tr>
</thead>
<tbody>
<tr>
<td>• designing suitable tasks and worksheets, embodying a purpose (teacher skill);</td>
</tr>
<tr>
<td>• exploiting interactivity;</td>
</tr>
<tr>
<td>• viewing with intent; looking for certain features;</td>
</tr>
<tr>
<td>• reviewing images to seek further meaning;</td>
</tr>
<tr>
<td>• making comparisons, thinking about links;</td>
</tr>
<tr>
<td>• avoiding superficial interactivity or ‘clickiness’.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Modelling tools and simulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>• using the time bonus;</td>
</tr>
<tr>
<td>• investigative approaches to modelling;</td>
</tr>
<tr>
<td>• making the most of simulations – encouraging analytical and divergent thinking.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Graphing tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>• observing the graph qualitatively;</td>
</tr>
<tr>
<td>• reading values;</td>
</tr>
<tr>
<td>• describing variables;</td>
</tr>
<tr>
<td>• relating variables;</td>
</tr>
<tr>
<td>• predicting;</td>
</tr>
<tr>
<td>• mathematical modelling.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data logging</th>
</tr>
</thead>
<tbody>
<tr>
<td>• using the time bonus;</td>
</tr>
<tr>
<td>• exploiting opportunities for new experiments;</td>
</tr>
<tr>
<td>• active observation during real-time logging;</td>
</tr>
<tr>
<td>• evaluating measurement quality;</td>
</tr>
<tr>
<td>• analysing data using graphs.</td>
</tr>
</tbody>
</table>
Books which present ideas for activities or which, like this one, seek to develop pedagogy for ICT in science, offer practical support for exploiting the benefits of new technologies for science learners. Nevertheless, the success of this endeavour will depend on the extent to which science teachers can make these approaches work in their own lessons. Personal experimentation to develop confidence and knowledge of operational and application skills within one's own context and resources, is an important step in securing ownership of new software tools. These steps represent a progressive training agenda for the future.

Whatever the future brings in terms of software development, its classroom use will need to focus on the nature of activities for science learners. This will involve the design of carefully structured ICT activities and non-ICT activities to provide opportunities to link parallel activity through a science context. It will place a high emphasis on social rather than solitary modes of computer use. Science teachers will remain instrumental in designing learning experiences and in working with pupils to develop their understanding in science.

In the past, merely providing software and training has not always adequately met teachers' needs and so use of ICT in science classrooms has not fulfilled expectations. In our view, the development of appropriate pedagogy has lagged behind the delivery of training in essentially operational matters. We hope that this book is a contribution to the debate which seeks to define pedagogy for teaching science with ICT. Our ambition is to shift the debate towards a more productive consideration of the application of ICT tools that is essentially driven by the needs of the science curriculum.
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during the performance of acid-base titrations.' *Journal of Research in Science Teaching*, 30(9), 1149–68.


Newton, L. R. (1997) 'Graph talk: some observations and reflections on students data-logging.' *School Science Review*, 79(287), 49–54.


References


Glossary

ADC (analogue to digital converter) – an electronic device that converts continuous analogue signals into a digital code.

Analogue – a signal that can have a range of values. Example: a typical temperature sensor produces a voltage anywhere between 0 and 2.5 volts.

ASCII Code (American Standard Code for Information Interchange) – a system of digital codes for numbering all the alphabetic, numeric and graphics characters used in the electronic storage and transmission of information.

Attachment – a computer file that accompanies an e-mail message.

Bit – the smallest unit of a digital code, represented by ‘0’ or ‘1’.

Bitmap – a method of storing a screen image whereby the colour and brightness of each pixel on the screen is specified by a separate digital code.

Boot Up – to load a program into computer memory and start running it.

Buffer Box – see Interface

Byte – a group of eight bits making up binary code used to store digital information.

CD – a compact disc for storage of digital audio, which has developed other storage applications.

CD-ROM (compact disc read only memory) – a CD developed to store digital information (typically 650 MB) for reading only.

Chip – an integrated circuit component used in electronic equipment.

Client – a computer connected to a network.

Compression – a technique to reduce the storage space required by data files.

Cursor – a pair of crossed lines used in graphing software to locate positions on the graph.

Data-Logging – the use of electronic measurement sensors and electronic devices to record and store physical data.

Digital – a signal which has two possible values, represented by ‘0’ or ‘1’.

Digital camera – records photographs in an electronic form that can be transferred to a computer.

Digitized images – a photograph or image which is stored in the form of a collection of digital codes.

DTP (Desk top publishing) – software for combining text, graphics and layout to produce a document.
Glossary

E-mail (Electronic mail) – a process of sending messages in an electronic format between computers via the telephone network.

File Format – refers to the method by which data is organised when it is stored as an electronic file. The filename ‘extension’ indicates the format used; for example ‘doc’ for Microsoft Word files, ‘txt’ for plain text files; ‘jpeg’ and ‘tif’ for image files; ‘csv’ for numerical data.

Floppy disk – a removable magnetic disc used for storing data.

Gateway – an internet site that provides access to other selected and related internet sites.

Generic software – general purpose programs, such as word processors and spreadsheets; sometimes called ‘content-free software’.

Gigabyte – $10^9$ bytes of data.

Gradient – a measure of the steepness of a graph line.

Graphical User Interface (GUI) – a screen design allowing programs to be operated using a pointer controlled by a ‘mouse’, minimizing the use of the keyboard.

Hard Drive – magnetic storage disc within the computer whose storage capacity is measured in gigabytes (1 gigabyte = $10^9$ bytes).

Hardware – a term used to describe electronic machines such as computers, monitors, printers, scanners, cameras, etc.

Hyperlink – these are signified by icons or ‘hot’ words (usually underlined and in a blue colour) on web pages; when clicked, they make the display change to a different web page or file.

Hypermedia – software which makes use of hyperlinks.

Hypertext – a text format used for web pages; it includes codes needed for controlling the appearance of text and graphics and for making links to pages or files defined by hyperlinks.

Icon – a small picture which represents an action or command in a computer program.

Interface – a box containing electronic circuits used for connecting sensors to a computer.

Internet – the global communications network enabling computers to share information in an electronic form.

Intranet – a network of computers for sharing information within a limited community, e.g. a school or local education authority. Usually with a gateway to the internet.

Iterative model – a mathematical model involving many repetitive calculations in small steps.

Kilobyte – $10^3$ bytes of data.

Logical operator – Boolean terms such as AND, OR which are used to define searches in databases and in internet search engines.

MBL – microcomputer-based laboratories – term widely used in the USA to describe data-logging techniques.

Megabyte – $10^6$ bytes of data.

Menu – a list of available options within software which can be selected typically by using a mouse.

Mouse – a hand-controlled device used to operate computer software through a Graphical User Interface.
Multimedia – an approach to information presentation on computers, which uses a
dynamic mix of graphics, sound, text, still, and moving images.

Network – a system of computers that are connected together and which can
communicate for sharing information and programs.

NGfL (National Grid for Learning) – a UK-based internet gateway providing
information and support material for all those connected with education.

Parallel – a method of connecting devices, such as a printer, to a computer and
involving at least eight electrical signals simultaneously.

Peripheral – devices such as printers and scanners which are connected to the
computer.

Platform – a term used to describe a complete type of computer system, comprising
hardware and software (e.g. Macintosh, IBM PC).

RAM (Random Access Memory) – memory in the computer which can be used to
both write (store) information and read information under the control of the user.

ROM (Read-Only Memory) – computer memory that acts solely as a store and
which can be accessed but not be amended by the user.

Search engine – a software facility used in the internet and in CD-ROMs which
allows searching of the resource without using the whole index.

Secondary data or derived data – data which is calculated from simpler versions of
data; for example 'speed' which is calculated from 'distance' and 'time'.

Sensor – a device used in data-logging for making measurements of physical
parameters such as light intensity, pressure, temperature.

Serial – a method of connecting devices, such as a printer, to a computer and
involving a single digitally coded electrical signal.

Server – a powerful computer which is central to a computer network and which acts
as a store of files and programs.

Software – computer programs that provide instructions that enable tasks to be
performed by the computer.

Vector graphics – a method of defining a screen image as a series of drawing
instructions.

VTC (Virtual Teacher Centre) – a part of the UK National Grid for Learning
providing resources and support materials for teachers.

Web page – a page of information designed for presentation on a computer screen.


WWW (World Wide Web) – a collection of information sources available on the
internet.

Web-authoring software – software for designing web pages.

WIMP – an acronym used to describe software driven by Windows Icons Mouse
and Programs.

Zoom – the process whereby a rectangular portion of a graph or image becomes
magnified on the screen.
Suggestions for further reading and practical advice

Note: Development and research into the educational uses of ICT is fast-moving and consequently materials can become rapidly outdated. The following sources are selected because we have found them to be of particular value.

Materials offering practical advice and ideas


On the internet

www.rogerfrost.com – a wealth of information and ideas to support ICT in science.
www.ase.org – Association for Science Education website offering links to other useful web sites and publications.
www.becta.org – British Educational Communications and Technology Agency website with information on research projects, resources and links to other useful sites.
www.ngfl.gov.uk – the UK National Grid for Learning: a gateway to information and resources for all involved with education. Includes a valuable Learning Resource Index and access to the virtual teacher centre (VTC).
Books offering theoretical perspectives sometimes exemplified with practical examples


Software resources

The following list of software is generally suitable for science teaching. It is not intended as a comprehensive or recommended collection of titles, but most of the items were consulted during the preparation of this book. Readers wishing to obtain the latest reviews of science software are recommended to visit www.rogerfrost.com.

Information systems
Encarta (Microsoft)
Chemistry Set 2000 (New Media Press) www.new-media.co.uk
Patterns in Chemistry (Anglia Multimedia) www.anglia.co.uk
Eyewitness Encyclopaedia of Science (Dorling Kindersley) www.dk.com
Redshift 2 (Maris Multimedia) www.maris.com
Exam Tutor Series – Biology, Chemistry, Physics (Granada Learning) www.granada-learning.com
ViewPoint (Logotron) www.logo.com

Publishing tools
Microsoft Office (Word, Publisher, PowerPoint)
Hyperstudio (TAG) www.tagdev.co.uk
Illuminatus (Digital Workshop)

Visual Aids
Electricity and Magnetism (Anglia Multimedia) www.anglia.co.uk
Cell City (Anglia Multimedia)
Scientific Processes (Anglia Multimedia)
Multimedia Motion (Cambridge Science Media) www.csmedia.demon.co.uk
Multimedia Sound (Cambridge Science Media)
Multimedia Science School (New media) www.new-media.co.uk
Bodyworks (Guildsoft)
The Ultimate Human Body (Dorling Kindersley) www.dk.com

Calculating tools
Excel (Microsoft)
Insight 3 (Logotron) www.logo.com
Warwick Spreadsheet System (Aberdare Publishing)
Suggestion for Further Reading/Advice

Modelling tools
Excel (Microsoft)
Insight 3 (Logotron) www.logo.com
Modellus (Institute of Physics) post16.iop.org/advphys

Simulations
Crocodile Physics: (circuits, optics) www.crocodile-clips.com/education
Crocodile Chemistry (reactions) www.crocodile-clips.com/education
Multimedia Science School: diffusion, food webs, Haber, mixing colours, rates of reaction, states of matter, terminal velocity, waves (New media) www.new-media.co.uk
Force and Motion (Fable Multimedia) www.fable.co.uk
Oscillations and Waves (Fable Multimedia) www.fable.co.uk
Science Explorer 1 and 2 (Granada Learning) www.granada-learning.com

Graphing tools
Insight 3 (Logotron) www.logo.com
Graphical Analysis (Pasco) www.pasco.com

Data Logging
Insight 3 (Logotron) www.logo.com
ICT activities for science 11–14 (Heinemann) www.heinemann.co.uk
LogIT Lab (DCP Microdevelopments) www.dcpmicro.com
Sensing Science (Data Harvest) www.data-harvest.co.uk
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This booklet is the fourth edition of a guide for teachers which seeks to exemplify appropriate use of data-logging techniques in practical science. The emphasis throughout is upon investigative approaches which encourage pupils to think about their data. The introductory pages explain this rationale and the pupils' worksheets contain the minimum of technical detail in order to maintain a high profile for questions about the science.

A special innovation in this version of Datalogging Insight is the addition of a modelling feature, intended to facilitate the integration of modelling and practical activities.
Datalogging Insight

Teaching and Learning Guide

by Laurence Rogers
School of Education, University of Leicester

and Roger Frost
IT in Science Consultancy
Datalogging Insight Teaching and Learning Guide

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Part number: DATINS4

Datalogging Insight has a companion package for younger pupils, Junior Datalogging Insight, is also published by Logotron.

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Datalogging Insight (Insight version 4)
Developed by Laurence Rogers, Leicester University School of Education
Programmer: Martin Williams
Documentation: Laurence Rogers

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Julian Pixton (Logotron)

Laurence Rogers
School of Education, Leicester University
The ‘Teaching and Learning Guide’ describes the principles which underlie the use of Datalogging Insight and some of the contexts for which the program was designed. It also contains many ideas for using Datalogging Insight in laboratory science. The guide is intended for selective rather than sequential reading and teachers are encouraged to dip into the various sections according to their needs and interests.

Detailed explanations of the variety of features of Datalogging Insight are given in the accompanying ‘Program Guide’ which also contains practical information about setting up the software and necessary hardware.

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Datalogging Insight is a learning resource for science education, providing a comprehensive environment for integrating the process of measurement in practical science with thinking about numerical data. Datalogging Insight can be used with a variety of sensors, connected to a microcomputer through a choice of different manufacturers' data-logging hardware systems. It can also be used as a general purpose mathematical tool for developing models for describing data. It helps pupils get more out of practical science by providing them with tools to extend their observations, encourage experimentation and prediction, and link theory with experiment. It is designed for a range of users with different levels of skill and confidence in computers: For the novice, results are easily obtained with the minimum of fuss; for the sophisticated user, Datalogging Insight can meet the demands of many complex tasks.

Datalogging Insight consists of the following:

CD ROM:

Datalogging Insight
- for recording and graphing signals continuously from analogue sensors.
- for timing events and measuring the motion of moving objects using digital sensors.
- for handling numerical and text data entered through the keyboard.
- for building formulae and mathematical models.

Insight Laboratory (Windows version only)
- interactive tutorials explaining datalogging and modelling techniques.
- interactive screen guides to a range of practical experiments.

Set-Up files
- for customising the program to make it ready for particular tasks.

Sample datafiles
- ready for classroom activities.

BOOKLETS:

Teaching and Learning Guide
Teachers' notes and ideas for activities.

Program Guide
Detailed explanations of the programs.

Skills Reference Card
Prompts for setting up and for using analysing tools.

For data-logging activity using Datalogging Insight, further hardware items are needed: data-logger or interface box sensors laboratory apparatus

Details of these items are given in the activities section of this guide.
Apart from the computer itself, the basic hardware needed for monitoring and measurement are sensors, interfaces and data-loggers. A sensor converts a physical quantity into an electrical signal which is connected to the computer via an interface or data-logger. Most systems allow up to four sensors, of the same or different type, to be used simultaneously.

The function of an interface is to make the electrical signals from sensors compatible with the computer. A data-logger performs a similar function but its circuits are more sophisticated allowing it to collect and store information from sensors even when it is not connected to the computer. For long-term experiments, or those performed away from the computer, this can be very useful, and also allows the computer to be used for other purposes.

Sensors are available for measuring a variety of different physical quantities (e.g. temperature, light, voltage, pressure etc). Details of their physical properties and mode of operation are provided by the manufacturers. Here it is helpful to note that there are two fundamentally different types:

An analogue sensor produces a variable electrical signal which can take many different values between certain limits (usually from 0v to 1v or 2.5v). Measurement with this type of sensor is very familiar since we are so accustomed to taking a range of readings from conventional instruments such as a voltmeter, thermometer and a ruler. These are all 'analogue' instruments.

A digital sensor is a switch-type device which produces a signal at one of only two levels, low or high (usually 0 volt and 5 volt). These two levels are often taken to indicate OFF and ON respectively. The commonest examples of digital sensors are light gates, pressure pads, and electrical switches. These are also familiar through their traditional use with conventional electronic stop-clocks and timers.

There are two main methods of collecting the information from sensors: Continuous synchronised measurement and single 'snapshot' measurements. Datalogging Insight is designed to exploit the distinctive properties of both types of measurement.

Most hardware systems allow you to use simultaneously up to four similar or different sensors. The interchangeability of sensors between different manufacturers' systems is generally quite restricted, so your choice of interface or data-logger usually determines the range of sensors you will be able to use. When you use Datalogging Insight for the first time, you will need to specify which hardware system you are using. (See Program Guide page 23). The program then adjusts to work with the range of sensors peculiar to the system. Most systems also allow Datalogging Insight to automatically identify the particular sensors you have connected.
New Approaches to Practical Work with ICT

**Datalogging Insight** is designed to support practical work by performing these tasks:
- Collecting data from sensors.
- Displaying the data in graphical form.
- Storing data in computer memory.
- Processing data; i.e. performing calculations.

For each type of task the program has a variety of features which provide opportunities for enhancing the skills of observation, measurement and analysis which are so important to practical work.

**Collecting data**
Continuous recording of results. Students can observe and measure rates of change, gradients of graphs, sudden changes and discontinuities.

Simultaneous measurements from several sensors may be made. Showing the data on a graph while the experiment is in progress reinforces the link between the experiment and results. Links between different variables may also be explored.

Data may be collected over long periods of hours or days, liberating experiments from some of the restrictions normally imposed by a school timetable or working hours.

Data can be collected over short durations allowing rapid changes and short-lived events to be recorded in detail.

A data-logger permits the remote collection of data away from the computer allowing experiments to be sited in locations which are not convenient for computers. This is well-suited to longer term experiments and also frees the computer for other activity.

The time between and during events indicated by digital sensors can be measured very precisely. These are quickly calculated into derived quantities such as velocity and acceleration.

**Displaying and exploring data**
Aids for display and analysis are key features of the ‘added value’ which **Datalogging Insight** gives to data and they provide a rich variety of new activities for exploring data.

There is a choice of display formats: graph, bar chart, table, model, large digits and bar display. Data can be viewed in a variety of informative ways using colour-coding, zoom effects, captions, joining points etc. These can help students see more clearly the important features of data and look for patterns and trends.

A range of analysing aids use cursor lines which can scan the whole graph area using the computer mouse as a control. The essence of analysis is finding out more information from the data; **Datalogging Insight** assists this by providing instant and accurate readouts from the graph of features such as co-ordinates, changes, gradient, ratios and areas.
A more advanced stage of exploration requires calculating aids which produce derived data. New data sets can be created through a choice of algebraic operations which help students identify mathematical descriptions of data. All these manipulations may be performed in the data table in the manner of a spreadsheet, but *Datalogging Insight* also offers two innovative methods which encourage an investigative approach to thinking about the data; calculations and curve fitting techniques may be applied directly on the graph, and mathematical 'models' may be built for generating data which replicates experimental data.

**Monitoring and control**
Control technology involves automated systems which often use sensors for monitoring an environment and microcircuits for processing the information and controlling machinery. In many instances, computers are used for the processing and control activity. *Datalogging Insight* illustrates how this is done at a simple level by using the signals from sensors to control a simple output device like a motor or light bulb. The task for students is to analyse the problem and specify the parameters and logic used by the program. A companion program, *Control Insight*, also available from Logotron, provides a much more sophisticated environment for designing solutions to control problems.

**Spreadsheets for handling data**
Spreadsheet programs are widely used in industry, commerce and in education. The spreadsheet table in *Datalogging Insight* is useful for storing information from science experiments where sensors are not appropriate; measurements from manual instruments, or perhaps the results of surveys can be typed in directly from the keyboard. The searching, sorting and graphing facilities are the important tools for exploring patterns in the data.

**Modelling**
The process of interpreting meaning from experimental data can be greatly assisted by synthesising results with mathematical models and then comparing the two types of data. *Datalogging Insight* offers a unique modelling system for building such models and the integration of this with the graphical and table analysis tools allows their properties to be explored with clarity and ease. The special appeal of a model for generating data is that the scientific principles underlying the phenomenon can be identified through mathematical expressions. Carefully designed models can illustrate the links between first principles and a sophisticated phenomenon in a sequence of easy stages. Models may be designed and built in predictive mode, before the experiment is performed, or in confirmatory mode after experimental data has been collected. In either case, the process of comparing the model data with experimental data provides valuable opportunities for prompting thinking about the science involved.
Observation, measurement and analysis

Observation, measurement and analysis are at the heart of practical activity in science. The previous section indicated several features of Datalogging Insight which offer fresh opportunities for exercising those skills.

These special features have implications for the way in which students can learn from practical work and they also provide teachers with new opportunities for managing students' activity. The computer facilitates a shift in emphasis away from the mechanical collection of data towards its interpretation; this leaves time for more attention to be given to observation. For example, the immediate presentation of a graph, while results are being collected, provides students with a qualitative overview of the data without the need of handling numbers or tabulating data. A quantitative analysis of the data might be a subsequent activity, but the initial reporting of the data is in an unsophisticated qualitative form. As a first activity students can inspect and select what is of interest on a graph, and appraise its significance. The minimal delay between doing the experiment and seeing and evaluating the results encourages an interactive approach; students might first speculate about the results and then test their prediction; their speculation might also be informed by building a model in advance of the experiment.

The topic of 'motion' enjoys special benefits from using the computer as a combined timer and calculator. Derived quantities such as velocity, acceleration and kinetic energy are available instantly, inviting exciting innovations in teaching approach. For example, students may explore the factors in an experiment which affect these quantities directly, without the need for numerous calculations.

Patterns in data are readily revealed when displayed visually; maximum values, minimum values, a general trend, smooth changes, sudden changes, rates of change all show up clearly on a graph. Studying the curvature or straightness of a graph gives valuable information about the connection between the quantities plotted. Students can devise or make a guess at a simple mathematical model for a relationship and test it by matching the curve or straight line to the actual data. In this they are required to exercise judgement and have freedom to adjust parameters and constants.

When to use ICT

A key concept in planning the use of ICT in science lessons is to identify appropriate use. Sometimes it is appropriate to augment or substitute traditional methods with ICT, but one must be cautious about displacing successful conventional practice without a clear rationale. The benefits of ICT need to be clearly identified and evaluated against objectives for teaching and learning. This guide attempts to give a vision of such benefits.

Enhancing traditional practice

To make effective use of sensors and computers, it is not necessary to adopt a revolutionary style of teaching. When taking the first steps in using a computer in the laboratory, many teachers feel most confident in using it simply as a demonstration aid. It has a number of benefits to offer this traditional role. A successful demonstration requires good communication and interaction with students. The computer can assist this by allowing the whole class to observe experimental effects on a bold and colourful screen display. Again, the computer's 'real-time' display process can greatly speed up discussion of the results. Analysing aids and curve-fitting facilities simplify the process of searching for patterns and meaning in results.
ICT and Scientific Investigation

Many modern science courses encourage students to explore their own ideas through an investigative approach in which they are given a large measure of responsibility for the design and conduct of experiments. Some of the most exciting benefits of using computers in practical science are realised when pupils, working in small groups, take charge of the activity. In a variety of ways, the computer is a natural tool for investigative work because of its flexibility and interactive properties. For science investigations requiring measurement, Datalogging Insight is ideally suited, because it simplifies many aspects of collecting and displaying data and encourages exploration and initiative.

In order to succeed, students need to have a good awareness of the range of tools provided in Datalogging Insight, an understanding of useful techniques with them and ideas of the sort of questions which can be posed about data. The Skills Reference Card gives many suggestions for useful questions and techniques for gaining answers.

Extensive discussion of the principles which underpin the appropriate use of ICT in science teaching may be found in “Teaching Science with ICT” by Newton and Rogers (Continuum Books, London, 2001).
Tools and Skills for Analysing Data

Datalogging Insight offers three sets of tools for helping students gain more information and insights into their data:

**Viewing aids** on the 'View' menu provide a choice of methods for presenting the data and information on the screen.

- **Graph** shows a graph of the data
- **Model** shows a model representing the data
- **Table** shows a table of the data
- **Chart** shows a bar chart of one channel of data
- **Notes** shows notes about the experiment or model

**Control Panel** for controlling the appearance of data and reading the data

- **Digits** shows data values in a large digits format
- **Bars** shows the magnitude of data as a bar for each channel
- **Toolbar** for controlling graph and table features
- **Status bar** shows information about program features

- **Axes** for adjusting graph axes and plotting features
- **Zoom** gives a magnified view on the graph
- **Zone** highlights a portion of the graph
- **Caption** is for adding notes on the graph

**Analysing aids** on the 'Analyse' menu allow students to read off a variety of different types of information from the graph.

- **Readings** gives readings off the graph
- **Change** gives the size of changes
- **Interval** gives time or X axis interval
- **Difference** gives the difference between two readings
- **Rate** gives an average rate of change
- **Gradient** gives the slope of the graph
- **Average** gives average values
- **Ratio** compares two items of data
- **Area** gives the area under a graph
Calculating aids on the ‘Data’ menu generate new data by performing calculations on data obtained from sensors.

- Formula calculates new data
- Smooth plots a smooth version of data
- Trial fit matches a formula to the data

Aids for editing and selecting data use a simple system of highlighting rows or columns of the table. A highlight is set up or cancelled by clicking or dragging in the ‘Item’ column. The editing options let you decide which rows of data are included in, or excluded from the screen displays.

- Channels view or edit channel definitions
- Constants view or edit constant definitions
- Delete all data deletes all the data
- Delete calculated data deletes data calculated by formulae
- Delete last item deletes the last row of data
- Delete selection deletes just selected rows
- Clear selection removes highlights
- Show all show all rows of data
- Show selection show selected rows only
- Hide selection hide selected rows
- Copy picture saves graph, table, model or chart as a picture
- Copy data saves data to clipboard

Searching and Sorting aids allow rows of data to be selected or sorted in numerical or alphabetical order.

Each tool has been designed with particular purposes in mind, and the experiments outlined in this booklet have been chosen to illustrate the range of these. It is helpful to associate each tool with a certain type of question which is useful to ask about data obtained in an experiment. The Skills Reference Card sets out a series of inquiries which can be applied to a wide variety of practical investigations. A particular tool is identified with each type of inquiry. Some tools are more sophisticated than others and demand different levels of skill for successful use. For general guidance skills can be divided up into three levels:

**Beginners’ level:**
Taking readings from a graph.
Showing a column of results as a bar chart.
Replaying the events of an experiment.
Observing and describing patterns in results.
Zooming in to see your results closely.
Sorting a column of results into order.
Finding out how long a change took.
Recognising simple patterns.
Finding out how big the change was.
Medium level:
Finding out which graph has the highest overall level.
Adding a new column to the Table.
Inserting values into the Table.
Removing the random 'noise' on a graph.
Calculating the average or total of several values.
Plotting a graph of results.
Comparing different parts of a graph.
Joining points with a smooth curve.
Finding out the pattern of change.
Using cursors to obtain readings.
Finding out the rate of change.

Expert level:
Looking for a relationship between variables.
Using 'Trial fit' to find and describe the pattern in the results.
Describing a relationship with a formula.
Calculating secondary data.
Highlighting selected rows.
Simulating some data to match a set of results.
Editing the appearance of the 'Table' using the 'Hide' and 'Show' options.
The Windows version of *Datalogging Insight* is accompanied by *Insight Laboratory*, an interactive tutorial guide which may be selected on the 'Help' menu. Its use provides an efficient means of acquiring a basic core of skills from which the more advanced skills of interpreting data and seeking scientific explanations may develop. *Insight Laboratory* is based on the Open Integrated Learning System (OILS) specification which incorporates facilities for monitoring performance, diagnosing errors and providing remedial advice.

**Setting up the computer**
This module gives general guidance on how to set up the software and hardware.

**Lessons**
There are ten lessons in basic skills, each requiring about 15 minutes to complete. The skills represented increase in sophistication as you work through the list.

<table>
<thead>
<tr>
<th>Lesson</th>
<th>Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Looking at data</td>
<td>Controlling the graph display, using zoom</td>
</tr>
<tr>
<td>Reading data</td>
<td>Using the cursors</td>
</tr>
<tr>
<td>Looking at changes</td>
<td>Using the 'Bars' display</td>
</tr>
<tr>
<td>Measuring changes</td>
<td>Using the 'Change' and 'Interval' tools</td>
</tr>
<tr>
<td>Looking at graph shapes</td>
<td>Describing and measuring rate of change</td>
</tr>
<tr>
<td>Fitting graph shapes</td>
<td>Using 'Trial fit' to fit curves</td>
</tr>
<tr>
<td>Looking for connections</td>
<td>Reselecting the axes and describing variables</td>
</tr>
<tr>
<td>Calculating new data</td>
<td>Building formulae</td>
</tr>
<tr>
<td>Exploring data in the table</td>
<td>Building formulae, searching and sorting</td>
</tr>
<tr>
<td>Building a model</td>
<td>Defining variables, constants and formulae</td>
</tr>
</tbody>
</table>

Each lesson presents information, explanations, questions, tasks and a report. Forward progress generally requires correct responses to the questions, but most of the questions allow up to three unsuccessful attempts before permitting progress to the next task. There are several types of question and task:

- **Choice**: Choose one of two possible answers.
- **Value**: Type in a numerical value.
- **Description**: Type in a sentence.
- **Multiple answer**: Identify the correctness of four statements.
- **Operation**: Perform an operation with *Datalogging Insight*

Choice, Value and Operation tasks are each awarded one mark on a correct first attempt. (Second or third attempts are not awarded any marks.) Description questions can be awarded up to two marks, but this has to be done by a teacher. Multiple answer questions are awarded up to four marks, one for each correctly annotated statement. At the end of each lesson the total mark is displayed together with a profile of marks for the particular skills exercised.

**Experiments**
The ten experiments illustrate how to apply skills learned in the lessons. They can be used as a direct support for practical work involving data-loggers, or as tutorial, revision and practice aids for analysing and interpreting graphs. The experiment topics have been chosen, with modest apparatus requirements in mind, to exemplify the range of analysing techniques with *Datalogging Insight*.
### Experiment

- **Evaporation and Cooling**
- **Liquid and Solid**
- **Enzymes and Temperature**
- **Photosynthesis**
- **Current and Voltage**
- **Radioactive Decay**
- **Rate of Reaction**
- **Pendulum Motion**
- **Velocity in Free Fall**
- **Force and Acceleration**

### Example skills

- Using zoom, cursors, bars; measuring changes
- Measuring time interval and rate of change
- Smoothing data, identifying trends
- Changing axes, measuring ratios, describing variables
- Fitting curves, measuring ratios and time interval
- Measuring time interval and rate of change
- Describing variables, calculating new data
- Calculating new data, fitting curves
- Calculating new data, describing variables

Each experiment module presents an introduction, instructions for setting up the apparatus, program, data-logger and computer connections, analysing tasks and questions, and a set of sample data.

### Suggestions for using Insight Laboratory

There is no one prescribed method of using the program; it can be used for a number of purposes and in a variety of ways in the classroom or for private study. Teachers will find the program useful as a means of INSET for developing their own confidence in using Datalogging Insight and in gaining vision of the learning possibilities for the analysis of data acquired with the aid of data-loggers. However the program is mainly designed for independent use by pupils working as individuals or in small groups. Its use can be scheduled either during or outside normal lesson times. The demands on the teacher for supervision and support of pupils should be minimal.

The ten lessons in basic skills can be used for:
- teaching pupils the basic skills for analysing data with Datalogging Insight.
- enabling pupils to revise these skills after a period of disuse.
- helping pupils to learn useful questions which can be asked when analysing experimental data.
- giving all pupils in a class a common core of training experience in using Datalogging Insight.

It is not necessary for all pupils to use all the lessons. For pupils at Key Stage 3, the first four lessons will suffice. These give a grounding in the basic techniques for viewing the data making qualitative observations and taking simple measurements. The later lessons are more appropriate at Key Stage 4 and beyond, giving pupils ideas for exploring data and seeking relationships between variables.

The experiment modules can be used for providing:
- on-screen instructions and reminders for performing a data-logging experiment.
- tutorials in analysing techniques for use before or after an experiment.
- revision and practice of analysing techniques on previously acquired experimental data.
- illustrations of suitable questions for exploring experimental data.

Throughout the use of the lessons and experiment modules, a Help button gives access to reminders on how to use the graphing tools in Datalogging Insight. Pupils can be encouraged to use this facility for quick revision. Generally, the help topics are closely related to the current task.
Activities with *Datalogging Insight*

The selection of activities presented in this manual has been chosen to illustrate the variety of uses of *Datalogging Insight*. Some are designed as introductory activities for beginners whilst others are better suited to expert students. Topics have been chosen from biology, physics and chemistry, and should find ready application in most science syllabuses at secondary level.

**Sensing and Modelling Activities**

1. Evaporation and Cooling*
2. Radiation
3. Big and Small Animals
4. Breathing
5. Fabrics and Light
6. Enzymes and Temperature*
7. Photosynthesis*
8. Current and Voltage*
9. Pressure and Temperature
10. Radioactive Decay*
11. Reaction Rate*
12. Pendulum Motion*
13. In Control

**Skill level**

- Beginner
- Medium
- Medium /expert
- Expert

**Features used**

- Readings
- Change, Interval
- Change, Average
- Snapshot, Caption
- Smooth, Gradient
- Remote logging
- Define, Trial fit
- YX graph, Define
- Ratio, Trial fit
- Smooth, Rate
- Overlay, Trigger, Define
- Control

**Timing and Modelling Activities**

14. Reaction time
15. Speed
16. Velocity in free fall*
17. Force and acceleration*

**Skill level**

- Beginner
- Medium
- Expert

**Features used**

- Bar chart
- Graph, Trial fit
- Average, Trial fit

**Spreadsheet Activities**

18. Building bridges
19. Cereals and nutrition
20. Periodic table
21. Planets

**Skill level**

- Beginner
- Beginner /medium
- Beginner /medium

**Features used**

- Keyboard entry, Graph
- Keyboard entry, Sort
- Sort, Bar chart, Graph
- Sort, Bar chart, Trial fit

Titles with an asterisk (*) are featured in *Insight Laboratory*.

The format of the following pages is intended to help students acquire and practice a range of skills for setting up experiments and analysing the results.

For each activity, a problem is posed and students are encouraged to think about the design of their experiment. Specific instructions are kept to a minimum so that attention can be focused on the purpose of the experiment and on suitable questions for interpreting the results. Common setting up procedures and methods of using the software tools are detailed on the *Skills Reference Card* which is conveniently used alongside the activities pages. Together, these should support students in setting up and using the software without too much additional direction.

To help students get started, they can load a Set-up file to configure the program settings. For each experiment, the *Datalogging Insight* software includes a Set-up file which has been pre-configured for the experiment. For the spreadsheet activities complete data sets are provided ready for analysis.
Evaporation and Cooling

Do you feel cold when you get out of a swimming pool? Does your skin feel cold when you spill after-shave or perfume on it?

Both these effects are due to evaporation, or drying up, of a liquid from your skin. When the liquid evaporates, it takes heat from your skin.

In this activity, you will study this effect by recording a temperature change on the computer screen. You can then examine different liquids to see if they produce the same effect.

Preparing the system

Set up the system
- Connect three temperature sensors to the interface.

Set up the Datalogging Insight software
- Open the Set-up file: 'Evaporation set-up' OR Select 'Sensing' from the 'Set-up' menu.
  - Click on the New button.
  - Set the Timespan to 15 minutes.

Set up the experiment and do a test run
- Assemble the apparatus as shown.
- Get ready to add a little alcohol to some cotton wool on the tip of one temperature probe.

What do you think you will see on the screen if you add the alcohol? Try this and see what actually happens over the next few minutes.

Does the timespan seem long enough? Change it if necessary.
Looking at Data

See the Skills Card for more details on using Datalogging Insight.

Readings

Take readings from your graph

What was the temperature at the start of the experiment?

How low did the temperature go?

Replay the events of the experiment

Check that the 'Bars' window is showing and move the cursor across the graph.

How did the alcohol affect the temperature of the probe?

Find out how big the change was

How much did the temperature change during the experiment?

Find out how long the change took to occur

How long did it take for the temperature to drop to its lowest point?

Comparing three liquids

Now do an experiment to find out which of three liquids has the greatest cooling effect.

You will need to think about how much liquid you will drop on the cotton wool. Will anything else make your experiment an unfair test? Do your experiment and, if necessary, repeat it until you are happy with the results.

Your graph is vital evidence that one of the liquids has a greater cooling effect. However, you need to back up your ideas with numbers. Take readings from the graph to find how big the temperature changes were. Also find out how long the changes took to occur. Write about your findings.

Mention any of the things you needed to do to make this a fair test of the three liquids.
Looking at a Model

- Open the Datalogging Insight file 'evaporation model'.

The model calculates the temperature of the liquid and the tip of the probe.

- Click on START to see the model run.

What are the similarities and differences between this graph of temperature against time and the one in your experiment?

What is the lowest temperature of the liquid?

The model calculates the heat lost by evaporation which depends upon the mass of liquid left on the probe and Latent heat of evaporation.

- Double click on the 'Latent heat' box and increase the value a little. Run the model again.

What happens to the lowest temperature of the liquid?

- Click on the 'Control panel' to display the amount of liquid 'm'. Notice that it diminishes as evaporation proceeds.

The rate of evaporation depends upon the volatility constant 'V'.

- Double click on the box for 'V' and increase the value a little. Run the model again.

How does an increase in the rate of evaporation affect the graph?

How do these new graphs help to explain the differences between the different liquids in your experiment?

- Double click on the 'Ts' box and increase the temperature of the surroundings a little. Run the model again.

How does an increase in the temperature of the surroundings affect the graph?
**Teacher's notes**

Summary of the ideas here

Liquids transfer energy to or from their surroundings as they change state. *Datalogging Insight* software and temperature probes will not only display information about this change as it occurs, but also allow you to take readings from a graph. Using the Change feature, you can show the net change in temperature, and compare the cooling effects of three liquids.

Programme of study keywords

Changes of state, evaporation, make predictions, analyse evidence.

Data-logging skill level: beginner

This activity runs through the skills required to start using a data-logging system. Taking readings, measuring a change, measuring a time interval and replaying the events of the experiment on a bar display are skills students will need to use in many activities in this series.

You will need

- Volatile liquids in dropper bottles
- *Datalogging Insight* software
- Clamp stands
- Three temperature sensors
- Elastic bands
- Computer
- Interface
- Cotton wool
- Interface cable

Hints and tips

To introduce this activity, you might talk about dogs panting in hot weather. You might get students to put a drop of alcohol on their skin and perhaps blow on it.

Get students to predict the shape of the graph they expect. After a minute or so of cooling, the temperature rises again. Whilst students are thinking about their prediction during the experiment, the data can be temporarily hidden from view using ‘Pause’ on the ‘Collect’ menu. A second click on ‘Pause’ reveals the hidden data.

Get the students to predict what would happen if you blew the alcohol with a hot hair dryer.

Start recording before adding the liquid to the probe.

Clamp the probes to give better control in the experiment.

Try the experiment with or without a swab of cotton wool. Or place temperature probes in round bottomed flasks and swab the outside of the flask with water or alcohol - then record in the usual way.

The Model

The model calculates the temperature of the evaporating liquid as a function of time. The calculations describe two simultaneous processes; evaporation causing a loss of heat and the intake of heat from the surroundings. Since the rates of change in these variables depend upon each other in a complex manner, the calculations are also complex, but the model comfortably handles the process through a series of iterative calculations of the small changes involved.

The user can choose the initial mass of liquid, its starting temperature, the temperature of the surroundings, the latent heat of evaporation and a volatility constant.

The assumptions in the model are:

1. The rate of evaporation is directly proportional to the mass of liquid remaining.
2. The amount of heat lost by evaporation is directly proportional to the mass of liquid evaporated.
3. The rate of heat gained varies in proportion to the temperature difference between the probe and its surroundings.

Further discussion can focus on the validity of these assumptions and what other variables might be considered in an improved model.

The calculations may be studied in more detail by invoking Step modelling mode (click on the ‘Time’ box and tick the ‘Single step’ box) or by examining the data in the table. Between each investigation, a duplicate set of calculated temperatures may be conveniently stored by selecting ‘Smooth’ on the ‘Data’ menu and clicking on STORE.
When the sun shines on the land and the sea they become warmer as you would expect. But which warms faster under the sun - the land or the sea? Which cools faster during the night time?

In this activity you will try to find this out. You will then think about how this might affect the climate in such places.

Preparing the system

Set up the system
- Connect the temperature sensors to the interface.

Set up the Datalogging Insight software
- Open the Set-up file: 'Radiation set-up'
- OR Select 'Sensing' from the 'Set-up' menu.
- Click on the New button.
- Set the Timespan to 30 minutes.

Set up the experiment and do a test run
- Assemble the apparatus as shown.
- Switch on the radiant heater and place the temperature probes in each material.
- Click on the START button and take readings for a few moments. Click on STOP.

Does the screen show that the temperature rises? If not, check your settings and connections.

The experiment
Now do an experiment to find out how fast the land and the sea warm up and cool down during the day. Use the sensors to give you a graph of the heating and cooling.
You can use sand and water and perhaps also use damp peat. You will need to think about how far away your containers are from the radiant heater.

Is there anything else that you need to consider to make your experiment a fair test?
Looking at Data

See the Skills Card for more details on using Datalogging Insight.

Take readings from your graph

Was the temperature of each of your containers the same at the start of the experiment?

Find out how big the temperature change was when the sun was shining

How much did the temperature change over the first 5 minutes of heating?

How much did the temperature change over the next 5 minutes?

Measure the temperature change over more 5 minute intervals. What do you notice as you go from one 5 minute interval to the next?

Which container heated up faster? Which container heated up slower?

Find out how big the temperature change was when the sun went down

How much did the temperature change over the first 5 minutes of cooling?

Which container cools down faster? Which container cools down slower?

The city of York is on an island, the UK mainland, surrounded by sea, while the city of Moscow is in the middle of a large continent. Both cities are at the same latitude (about 55N).

How might the summer temperatures in York compare with Moscow?

How might the winter temperatures in York compare with Moscow?
Further Work

Find out whether the cooling is exponential (or otherwise) using the following procedure:

Subtract the ambient temperature from one of your graphs

- Click on the Formula button

If you are working on channel T1 and the ambient temperature is 16.5, build the formula 'T1 - 16.5' for the new set of data 'A'.

- Click OK.

The new graph line 'A' shows a cooling curve minus the ambient temperature. It will be parallel to graph T1.

You can rename the new channel 'Excess temperature' as follows:

- RIGHT click on 'A' on the Control Panel and select 'Edit...'.

See which curve fits the graph

- Click and drag the mouse to draw a 'Zoom' or 'Zone' box over the part of the 'A' graph you want to test.

- Click on the 'Trial fit' button to show the dialogue box.

- Click the channel button so that it reads 'Fit to A'.

- Click on 'Plot' and each formula in turn to see which give the best fit to the 'A' graph.

Which curve fits the graph?

What does this tell you about cooling?
**Teacher's notes**

**Summary of the ideas here**

Land and sea warm and cool at different rates. *Datalogging Insight* software and temperature probes will allow you to compare the rates of change by reading off net temperature changes over successive 5 minute intervals. The changing slope of the graph can be linked with the increases and decreases of temperature.

For more advanced work, it is an easy matter to see if the pattern of change will fit an exponential curve. Since the simple form of an exponential usually tends to be a zero value, it is best to subtract the ambient temperature before attempting to fit the curve.

**Programme of study keywords**

Energy transfer by radiation; planning, obtaining and analysing evidence.

**Data-logging skill level: beginner**

All but the advanced work here should be suitable for beginners. The skills used here are taking readings and measuring a temperature change in a given time.

**You will need**

- Trays, tins or beakers, water, sand, peat or soil
- Radiant heater or halogen 'security lamp'
- *Datalogging Insight* software, computer
- Interface, interface cable
- Two or three temperature sensors

**Hints and tips**

Get students to predict the shape of the graph they expect. Ask them how they will decide when to switch off the heater.

If you are using a cylindrical-type of radiant heater, place the containers in a circle on the bench with the heater at the centre.

Fix the temperature probes in the centre of the beakers or containers so that they do not touch the containers themselves.

You can use the gradient feature of *Datalogging Insight* to show how the rate of warming decreases over time. Select 'Gradient' from the 'Analyse' menu. As you move the cursor over the graph you can read off the gradient at any point.

You might try to find out how the water content of the peat affects its heating and cooling. You might also try to find out how different coloured containers absorb heat.
Have you noticed that babies are always wrapped up warmer than we are? Why do they need more covering than us? Is it something to do with their age? Or is it something to do with their size? Do you think that small animals have a harder time keeping warm than large animals? Think about an experiment you could do to show that smaller things cool faster than larger things.

Preparation

Preparing the system

Set up the system
- Connect two temperature sensors to the interface.

Set up the Datalogging Insight software
- Open the Set-up file: 'Animals set-up' OR Select 'Sensing' from the 'Set-up' menu.
- Open the Set-up file: 'Animals set-up' OR Select 'Sensing' from the 'Set-up' menu.
- Click on the New button.
- Set the Timespan to 20 minutes.

Set up the experiment and do a test run
- Assemble the apparatus as shown.
- Click on the START button, hold the temperature probe and take readings for a few moments. Click on STOP. Does the screen show that the temperature rises? If not, check your settings and connections.

The experiment
Now plan an experiment to find out how fast large animals and small animals cool down. Think about using two containers of hot water. Use the sensors to give you two cooling graphs. You will need to find a way to make the starting temperatures equal.

Is there anything else that you need to consider to make this a fair test?
Looking at Data

See the Skills Card for more details on using Datalogging Insight.

Replay the events of the experiment

Check that the 'Bars' window is showing and move the cursor across the graph.

Which container appears to have cooled faster?

See if your experiments started off at the same temperature

- Select 'Readings' from the 'Analyse' menu.

As you move the mouse over the graph, you will see the temperature readings in the control panel.

What were the highest temperatures for your two containers? Are they similar? Should they be?

Find out how big the temperature drop was

- Find the highest temperature reached on your graph and then measure the temperature drop over the next 5 minutes.

How much did the temperatures change over the first 5 minutes of cooling?

Find out which container stays the hottest overall

- Select 'Average' from the 'Analyse' menu.

- Move the mouse over the graph, until a vertical line is exactly at the start of the experiment.

- Double click the mouse button.

This should fix a line on that spot so that, as you move the mouse to the end of the experiment you will see the average value of each graph calculated for you. This tells you which graph has stayed the highest overall.

Which container stayed hot longer?
Looking at a model

- Load the Datalogging Insight file 'cube model'.

The model calculates the temperature of a body in the shape of a cube. The cube starts hot but gradually cools down because the surroundings are cooler.

*What is the starting temperature of the cube?*

*What is the temperature of the surroundings?*

- Click on START to see the model run.

*What are the similarities and differences between this graph of temperature against time and the one in your experiment?*

Notice that the model calculates the surface area and volume from the width of the cube.

- Double click on the 'width' box and reduce the width to 0.1 m\(^2\). Run the model again to see how quickly the smaller cube cools down.

*What does this demonstrate about the cooling of large bodies compared with smaller bodies?*

Investigate the effect of changing some of the other variables and values in the model. For example: starting temperature of the cube
temperature of the surroundings

\[ \Delta T = -k \frac{A}{V} (T - T_s) \cdot \Delta t \]
**Teacher's notes**

**Summary of the ideas here**
This activity shows how you can quickly see which of two containers has cooled the most by calculating the change in temperature. **Datalogging Insight** software and temperature probes will display variations in temperature as they occur.

The 'bar window' provides a rough indication of one container cooling more quickly than another. The 'Change' feature makes it easy to calculate the drop in the temperature even when the starting temperature is not the same for each container.

**Programme of study keywords**
Adaptation, energy transfer, planning, obtaining and analysing evidence.

**Data logging skill level:** beginner
The skills used here are taking readings and measuring the temperature change in a time interval.

**You will need**
- Tins or beakers
- Warm water
- **Datalogging Insight** software and computer
- Interface, interface cable
- Two temperature sensors

**Hints and tips**
Get students to predict the result, and the graph that they expect.

Fix the temperature probes in the centre of the beakers or containers. It is helpful to pre-heat the containers (as you might a teapot!) before adding hot water for the experiment.

There are endless variations on this experiment where you can apply the same analysis tools: cooling experiments, comparing different shaped containers, showing the effect of a draught, or covering with clothing, fur, foil and feathers.

**The Model**
The model is based on a cube shape in order to keep the formulae simple. The user can choose the starting temperature, the temperature of the surroundings and the width of the cube. The assumptions in the model are:

1. The rate of heat loss varies in proportion to the surface area of the cube and the temperature difference between the cube and its surroundings.

2. The rate of heat loss varies in proportion to the volume of the cube.

'k' is a general constant of proportionality.

Further discussion can focus on the validity of these assumptions and what other variables might be considered in an improved model.

The calculations may be studied in more detail by invoking Step modelling mode (click on the 'Time' box and tick the 'Single step' box) or by examining the data in the table. The model can be used to prompt useful discussion of the 'surface area to volume ratio' for mammals.
Breathing

In this activity you will see how your breathing is effected by exercise. You may use either of two types of equipment. The first is a breathing sensor consisting of a belt which straps around your chest.

The second is a position sensor attached to a spirometer. This can actually measure your lung volumes, but must be used with an expert on hand.

Using a Breathing Sensor

Set-up the system

- Connect the sensor to the interface.

Set up the Datalogging Insight software

- Open the Set-up file: 'Breathing set-up'
- OR • Select 'Sensing' from the 'Set-up' menu.
  - Click on the New button.
  - Set the Timespan to 1 minute.

Using a breathing sensor

- Connect yourself to the sensor and do a test run.
- Click on the START button and take several deep breaths. Click on STOP.

Does the screen show your breathing adequately?

If there is no response at all, check your settings and connections.
- Adjust the graph axis to show a larger deflection on the screen.

The experiment

- Now take readings of your resting breathing until you have a minute of steady, reliable readings.
- Do some exercise. Then, as you recover, record for another full minute.

Looking at Data

Replay the events of the experiment

How does the computer display your inspiration and expiration?

What was your breathing rate (breaths per min.) at rest and immediately after exercise?

Find out how long a breath takes

- Select 'Interval' from the 'Analyse' menu.
- Move the mouse over the graph, until a vertical line is exactly over the first peak.
- Double click the mouse button. This should fix the line on that spot.
- Move the mouse to the tip of the next peak and read the time taken in the Control panel at the left of the screen.

What was your breathing interval (time per breath) at rest immediately after exercise? Is the breathing rate steady?
- Find out by measuring several peaks on your graph.
Breathing

Using a Spirometer and position sensor

- Connect yourself to the spirometer and do a test run.
- Click on the START button and take several deep breaths.
- Click on STOP.

Does the screen show your breathing adequately?

If there is no response at all, check your settings and connections.

- Select 'Calibration' from the 'Set-up' menu.
- Open the spirometer so that the lung volume is at one of the higher settings.
- In the calibration box click on the top '<' button to record the high sensor reading.
- Type the actual volume setting into the 'High' box.
- Close the spirometer so that you reach one of the lower volume settings.
- Click on the low '<' button to record the low sensor reading.
- Type the actual volume setting into the 'Low' box.

The experiment

- Take readings of your resting breathing until you have a minute of steady, reliable readings.
- Do some exercise. Then, as you recover from the exercise, record for another full minute.
- Continue to take readings as your normal breathing returns.

Looking at Data

Replay the events of the experiment

How does the computer display your inspiration and expiration?

What was your breathing rate (breaths per min.) at rest and immediately after exercise?

Compare your breathing before and after exercise

- Select 'Change' from the 'Analyse' menu.
- Move the mouse over the graph, until a vertical line is exactly at the start of the breathing.
- Double click the mouse button. This should fix a line on that spot so that, as you move the mouse 30 seconds to the right you will see the change in volume calculated for you. This value is a measure of the amount of air you have inhaled and exhaled.

What was your tidal volume at rest?

How does your tidal volume change during and after exercise?
Looking at a model

- Load the Datalogging Insight file ‘breathing model’.

The model calculates the number of breaths per minute from the time taken for one breath.

- Click on START to make the model work.

Notice that when the time for one breath is 4 seconds the model calculates that the breathing rate is 15 breaths per second.

- Click on 'T' and adjust its value up or down and notice how the breathing rate changes.

What happens to the breathing rate if the time for one breath becomes longer?

- Hold the SPACE bar down and notice how the program plots a graph of the volume of inhaled and exhaled air against time.

Use your watch to find out how many seconds one breath of your own lasts.

- Double click on the 'T' box and enter this number as the 'Start value'.

- Set the independent variable to 't' (time) and run the model again. The program calculates and plots a theoretical graph of your breathing.

- Select 'Interval' from the 'Analyse' menu and measure the time from one peak to the next.

Does the graph accurately show the time that you measured for one breath?

- Explain what the graph means when the values are positive. What do the negative values mean?

Vo = Vo * sin(6.28 * B / 60 * t)

T

Time per breath

B = 60 / T

Breathing rate

V

Volume of air

Vo

T

Time

B

Breathing rate

Volume of air
Summary of the ideas here

Datalogging Insight software and a breathing sensor can show how breathing changes during and after exercise.

Breathing sensors come in different designs. There are custom breathing sensors or you can use a pressure sensor and a stethograph. They can show your breathing rate and depth very capably.

A spirometer can be connected to a position sensor (as you might to a kymograph) and not only show your breathing rate and depth, but also give absolute volumes, such as the tidal volume.

Programme of study keywords
Breathing, ventilation of the lungs, planning experiments, obtaining and analysing evidence.

Data-logging skill level: beginner
The skills required here involve using the bar display feature, measuring a time interval and measuring the change in lung volume. In the spirometer variation, the change in the graph is calculated and taken as a measure of how much air is inhaled and exhaled.

You will need
- Breathing sensor or position sensor and spirometer
- Datalogging Insight software and computer
- Interface and interface cable

Hints and tips
If you are using a spirometer, be sure you are familiar with the health and safety implications of using one.

The model
The model simply calculates breathing rate per minute from breathing interval in seconds. The user can choose values for the breathing interval ‘T’ and the maximum lung capacity ‘V0’. Initially the model is used in Free modelling mode so that values may be entered directly using the adjuster buttons on the ‘T’ box.

When ‘time’ is selected as the independent variable, the program increments time values automatically. The model assumes that the volume of exhaled and inhaled air varies sinusoidally. Further discussion can question the validity of this assumption and what other variables might be considered in an improved model.
Fabrics and Light

Which fabric makes the best lampshade?

Glass is a good material for a bulb of a lamp: Being semi-transparent it allows most of the light to pass through. In contrast, materials, such as the fabric used for lamp shades, are chosen because they reduce and diffuse the light.

In this activity you will use a sensor to measure the amount of light passing through several fabrics. You will use this information to decide which fabric might make the best lamp shade.

Set up the system
Connect a light sensor to the interface.

Start the Datalogging Insight software

- Open the Set-up file: ‘Fabrics set-up’
- Select ‘snapshot’ from the ‘Collect’ menu
- Select ‘Sensing’ from the ‘Set-up’ menu.
- Click on the New button.
- Show the table and chart windows only.
- Add a text column to the table with the name ‘Fabric’.
- Select ‘snapshot’ from the ‘Collect’ menu

Set up the experiment and do a test run
Arrange the equipment as shown.

- When you are ready to take a light level reading, click on STORE. Try this several times to see how the readings appear.
- Click STOP when you have finished your testing.

Measure how much light gets through the fabrics
Now decide how you will test the fabrics.

How will you hold them? Where will you place the light sensor?
How will you ensure that your measurements make a fair test?

Then take one or more readings, from each fabric. Enter the name of each fabric in the table.
Fabrics and Light

Looking at Data

See the Skills Card for more details on using Datalogging Insight.

Look at the readings you have collected

- Select ‘Readings’ from the ‘Analyse’ menu.

As you move the mouse over the chart you will be able to note down the readings from each fabric. You will also be able to compare them using the table.

Which material is the best for stopping light?

Which material lets the most light through?

Which material would you use as a lamp shade?

How does fabric thickness affect the light?

If you used several layers of fabric, you would expect the amount of light passing through to be less. Use the method of this experiment to find out precisely how the light depends upon the number of layers. Save your present data on disk, then delete it from the program (select ‘Delete all data’ from the ‘Edit’ menu).

- Select the ‘Graph’ window and choose the axes to show Light (Y axis) against Item (X axis). You can use the ‘Item’ number to represent the number of layers. Type the label ‘Number of layers’ for the Item axis.

- Select ‘Snapshot’ from the ‘Collect’ menu and take light readings for one layer, two layers, three layers, etc.

Does the light reduce in a regular pattern as the number of layers is increased?

How much does the light change every time you add another layer?
Looking at a model

Load the Datalogging Insight file 'fabrics model'.

The model calculates the intensity of light passing through an increasing number of layers of fabric.

- Click on START to see the model run.

What are the similarities and differences between this graph of light intensity against number of layers and the one in your experiment?

The model calculates the reduced intensity of the light on the assumption that each layer absorbs the same fraction of light entering it.

Does the graph confirm a prediction that more layers allow less light through?

How many layers are needed to reduce the light intensity to half its starting value?

The constant 'b' represents the fraction of light transmitted through one layer of fabric.

- Double click on the absorption box 'b' and increase the value a little. Run the model again.

How does this graph compare with the previous one?

How many layers are needed to reduce the light intensity to half its starting value?

From your experience here of changing 'b', would you expect a dark fabric to have a large or small value of 'b'?

Use 'Trial fit' to find out what sort of formula best describes the connection between the light passing through the fabric and its thickness.
Teacher's notes

Summary of the ideas here
Most data-logging experiments involve taking a series of readings over time. In others you may need to use the system as a meter and take a few discrete readings, say, of the amount of light passing through different fabrics.

This activity shows how you can access this feature of Datalogging Insight. You can use the skills gained here to attempt some other investigations mentioned below.

Programme of study keywords
Transparency, obtaining and analysing evidence.

Data-logging skill level: beginner
The skills required here involve setting up a data-logger and taking discrete readings using Datalogging Insight Sensing's Snapshot feature.

You will need
Labelled or numbered fabrics
Desk-lamp
Light sensor
Narrow card tube, to shield the sensor from extraneous light
Datalogging Insight software and computer
Data-logger, interface cable

Further ideas
There are several other simple investigations you might try using the same software skills - these are recommended for beginners:

Find out if some colours let less light through than others. Find the 'best' material for a window blind or the brightest material for a road sign. Find the 'best' material for a pair of sound-deadening ear-muffs. Compare the pH readings from some water samples.

Hints and tips
Stray light will affect the readings obtained, so place a short paper tube over the end of the sensor. The light sensor will now have a narrower range of view.

From the results, the students will need to choose the 'best' lamp shade material - deciding between the more opaque and the more transparent materials.

The model
The model calculates the intensity of light passing through an increasing number of layers of fabric. The calculations are based on the simple assumption that each additional layer of fabric reduces the light intensity by the same fraction.

The user can experiment with different values of the absorption constant 'b' and associate this with the opacity of the fabric. Between each investigation, a duplicate set of calculated temperatures may be conveniently stored by selecting 'Smooth' on the 'Data' menu and clicking on STORE.

Fitting a curve to the data yields an exponential format. The 'Trial fit' option calculates the absorption constant 'b' explicitly.

Discussion can focus on the validity of the main assumption and perhaps consider why a linear reduction in the intensity is less appropriate.
Enzymes and Temperature

The enzyme amylase is found in your mouth and your pancreas. It breaks down starch into sugar and is useful in manufacturing foods such as bread and cakes. You have been asked to find the temperatures at which the enzyme works best.

You can use the 'starch-iodine test' to do this. As the enzyme changes starch into sugar, the colour changes from dark blue to colourless - and the faster the reaction, the faster this happens.

You can monitor this happening by using a light sensor connected to a computer. As you try the reaction at different temperatures, you should see different graph shapes.

Set up the system

Connect a light sensor to the interface.

Set up the Datalogging Insight software

- Open the Set-up file: 'Enzymes set-up' OR
- Select 'Sensing' from the 'Set-up' menu.
- Click on the New button.
- Set the Timespan to 20 minutes.

Set up the experiment and do a test run

Arrange the equipment as shown.

Place 20 cm$^3$ of starch solution in a beaker arranged as shown in the diagram. Add 2 - 3 drops of iodine solution. Click on the START button and look for a trace on the computer screen. Add 5 cm$^3$ amylase to the beaker and give the flask a quick stir.

Is a trace visible on the screen? Is the trace near the bottom of the screen?

Does it move as the reaction takes place? What happens to the appearance of the solution during the reaction?

Make any adjustments to the set-up, change the light level, or change the volumes and strengths of your solutions. For the first experiment it will be necessary to warm the starch solution to 30 deg C. It will be helpful if the reaction at this temperature takes around 15 minutes.

The experiment

Now think about the experiments you will do to show how temperature affects the reaction. You will need to repeat the same experiment at two different temperatures. Between each of your experiments you should save your results on the disk so that you have two graphs.

You may put the graphs on the same axis as you do each experiment. You do this by first selecting 'Overlay' from the 'Set-up' menu. Each time you click on START to do a new experiment, a graph will be added to the ones already on the screen.
Looking at Data

See the Skills Card for more details on using Datalogging Insight.

Replay the events of the experiment
Write a sentence saying what happened and why the graph went up or down.

Find out how big the change was at each temperature

- Select ‘Change’ from the ‘Analyse’ menu.
- Move the mouse over one of your graphs, until a vertical line is at start of the experiment. Double click the mouse button. This should fix the line on that spot.
- Move the mouse to the right until the ‘Time’ in the ‘Control’ panel reads say, 5 minutes. Then record the change for that graph in the ‘Control’ panel.

Do this for the graph for each temperature in turn.

Does a low temperature give a small change?
Does a high temperature give a large change?
Is there a pattern between the temperature and the reaction rate?

Make a smooth graph line
If your graph is uneven you can remove some of the ‘bumpiness’ as follows:

- Select ‘Smooth’ from the ‘Data’ menu.

In the ‘Smooth’ dialogue box, select the channel which you want to smooth.
- Click on ‘Plot’ to show the smooth line. If you want a smoother line, click on ‘Plot’ again.

When you are satisfied with the line, click on STORE; the smoothed version of the data will be stored as a new channel.

At what temperature did you do this experiment?
Suggest why the graph was ‘bumpy’.

Add captions to the graph

- Click on the Caption button and enter the temperature value for the last experiment.
- Click the tick boxes to give a pointer, and fix the caption to the X value and channel.
- Click on ‘Place’ and use the mouse to:
  1. Position the pointer near the graph line. Click once.
  2. Position one corner of the caption. Click once.
  3. Position the diagonal corner of the caption. Click once.
Further Work

Find out how quickly the values are changing

- Select ‘Gradient’ from the ‘Analyse’ menu.

As you move the mouse over the graph, you can read off the steepness or gradient of the graph at different points.

When the graph is horizontal the gradient is zero and the values are not changing. A positive gradient tells you that the rate of the reaction is increasing. The larger the number, the faster the change.

What can you say about the gradient at the start and towards the end of the reaction?
Summary of the ideas here
The light sensor can be used like a colorimeter to follow a reaction such as where the 'starch-iodine' colour gradually turns to colourless. The reaction can be repeated at different temperatures, and the Datalogging Insight software will allow you to record each of these reactions as a separate graph.

In another activity in this series we used the software to measure the average gradient of each graph. This was taken as a measure of reaction rate. You can do that here but we have used 'the amount of change in a certain time' as a measure of rate.

With advanced classes you may also be able to see how the reaction rate changes during the course of a reaction. In other words, you can show that reaction rate decreases over time, due to the decreasing concentration of starch. You use the 'Gradient' feature of Datalogging Insight for this. It calculates the gradient at any point along the graph.

Programme of study keywords
Rates of enzyme-catalysed reactions, planning experiments, obtaining and analysing evidence.

Data-logging skill level: medium
The skills required here involve using the 'Overlay' feature where successive experiments are built up on the same axes. Using the 'Bar' display replays the events of the experiment, while 'Smooth' removes 'noise' from a graph line. To show the rate of reaction at any point you can use the 'Gradient' feature.

You will need
- 50 cm³ beakers
- Light sensor
- Thermometer or temperature sensor
- Measuring cylinders
- Starch(1%), iodine and amylase(1%) solutions
- Water bath
- Clamp stand, clamps and lamp
- Interface, interface cable
- Datalogging Insight software and computer

Hints and tips
It is essential that the amylase is fresh for its enzyme action to work.

Placing the lamp below the beaker helps to maintain the temperature of the liquid. The average temperature can be controlled by adjusting the height of the beaker above the lamp.

Record the temperature of the mixture during the reaction. You can also use a temperature probe.

It is much recommended that you save your results to disk between experiments. If there is an error, you will be able to recover easily by going back and opening the saved file.

This experiment is featured in Insight Laboratory. (Windows version only)
Photosynthesis

During photosynthesis, plants make food using water, carbon dioxide gas and light energy. As well as producing food, photosynthesis also produces oxygen gas. The process of photosynthesis can be represented like this:

\[
\text{Carbon dioxide + Water and light} \rightarrow \text{Food and Oxygen}
\]

In this experiment, you will be able to study the process by measuring the light level and the oxygen gas produced.

Using a light sensor, oxygen electrode and data logger, you can take measurements over a period of hours or days. A data-logger is useful for this because it can store the measurements automatically in its memory. You need to stop the oxygen produced being lost into the air. This is best done by using a plant under water so that the oxygen dissolves in the water before it escapes into the air.

Set up the system
Connect the light and oxygen sensors to the data-logger. Fix the light and oxygen sensors where they will not be disturbed during the experiment which will last for 24 hours.

Start the experiment
Find out how to get your data-logger to start taking readings on its own. For example, the data-logger may have a Start or Go button to press or it may even need to be programmed.

What do you think will happen to the light level during your experiment?
What do you think will happen to the oxygen level during your experiment?

Stop the experiment
When you have finished taking readings, stop the data-logger.

Download your readings from the data-logger
- Connect the data-logger to the computer in the normal way.
- Select 'Download' from the 'Collect' menu.
- Choose the most recent set of data stored in the data-logger. In a few moments your readings should appear on the graph.
Looking at Data

See the Skills Card for more details on using *Datalogging Insight.*

Replay the events of the experiment

- Check that the 'Bars' window is showing and move the cursor across the graph.

As you move the mouse from left to right, the bar shows how the readings changed in the experiment.

*Describe what happened to the light level during your experiment.*

*Describe what happened to the oxygen level during your experiment.*

*Which rises first, the oxygen level or the light level?*

*What might this tell you?*

Look at the changes in oxygen concentration and light level

*Do the two types of change occur at the same time?*

*Describe the connection between the changes.*

Make smooth graph lines

If your graphs appear rather jagged, select 'Smooth' from the 'Data' menu to create a smooth version of the data.
Looking at a model

- Open the Datalogging Insight file 'photosynthesis model'.

The model calculates changes in the oxygen concentration in an aquarium resulting from the daily cycle of daylight and darkness. The calculations are based on data for light level recorded in a real experiment over a period of seven days. This timescale has been compressed to less than five minutes to make the model practicable.

- Click on START to run the model.

Describe the similarities and differences between the graph lines for 'light level' and 'concentration'.

Try to devise a rule which predicts what happens to the concentration when the light level changes.

- On the Control Panel, click the data button for Oxygen to show the graph line of data collected in the experiment. You can compare this with the data calculated by the model.

Describe the similarities and differences between the graph lines for 'Oxygen' and 'concentration'.

In the model, the process which causes the concentration (of oxygen) to increase is affected by the constant 'p' and the process causing it to reduce is affected by the time constant 'k'.

Investigate the effect on the graph of altering the values of these constants. Make small changes only. Find out about the processes indicated by these constants.

\[ \Delta C = k \cdot (C_x - C) \cdot \Delta t \]

\[ C_x = p \cdot L \]

\[ \text{Light level} \]

\[ \text{production constant} \]

\[ \text{maximum concentration} \]

\[ \text{concentration} \]

\[ k \text{ time constant} \]

\[ t \text{ time} \]
Teacher's notes

Summary of the ideas here
Some experiments need to run for a long time before we can collect sufficient information from them. Monitoring photosynthesis is a good example of this.

This activity shows how you can leave data logging equipment to collect readings over a long period of time. In this example, we monitor the light and oxygen levels in an aquarium.

The 'Bars' window indicates how the oxygen level increases in tandem with the light level. If you have monitored readings for 24 hours or more, you should certainly be able to notice that the light level increases before the oxygen level.

Programme of study keywords
Photosynthesis; obtaining and analysing evidence.

Data-logging skill level: medium
The skills required here involve setting up a data-logger to work independently and to use the computer to fetch the data from it afterwards.

You will need
- Aquarium or pond with plant life
- Light sensor
- Oxygen sensor and oxygen electrode
- Data-logger, interface cable, Datalogging Insight software and computer

Hints and tips
Get students to predict the result, and the graph that they expect.

Instructions for using data-loggers vary between the different brands. All the latest devices can be started at the press of a button. Older data-loggers may need to be connected to the computer briefly before the experiment, so that Datalogging Insight can program them - or tell them, how long they should measure for and which sensors are attached (select 'Remote' from the 'Set-up' menu).

The membrane on the tip of an oxygen electrode is very sensitive to physical damage and most problems in our experience stem from such damage. You may be able to fix a piece of foam to it to protect it from a chance knock.

An oxygen electrode which has been stored for some months may need a change of electrolyte. After such a change it may take half an hour before it stabilises. There is no real need to calibrate the electrode with known oxygen concentrations, since the monitoring exercise focuses on changes rather than on absolute measurements.

This experiment is featured in Insight Laboratory. (Windows version only)

The model
The model is a gross simplification of photosynthesis but it does provide a focus for discussion of the two main influences on the oxygen concentration in the aquarium, one causing it to increase and the other causing it to decay.

The assumptions of the model are:
1. The maximum concentration of oxygen depends on the light intensity.
2. The concentration gradually decays exponentially.

The model successfully predicts the delay between the two sets of peaks, how the concentration does not instantly drop to zero when it becomes dark. The rate of production and rate of decay of oxygen can be controlled by the two constants in the model. Pupils can be encouraged to discuss possible physical and biological factors involved in these processes. Further discussion can focus on the validity of the assumptions and what other variables might be considered in an improved model.
Current and Voltage

An electric bulb lights up when an electric current flows through it. Many other components also produce a special effect when a current passes. For example, a coil of wire can produce heat and a magnetic field. Whatever the effect of current, you need to connect a voltage, say from a battery, to get the current to flow. The size of voltage needed will vary from one component to another according to its resistance. Not only this, some types of component become better or poorer conductors as the current is allowed to increase.

In this activity you can investigate the connection between voltage and current for a variety of different components.

Set up the system
Connect a voltage sensor and a current sensor to the interface.

Set up the Datalogging Insight software
- Open the Set-up file: OR Select 'Sensing' from the 'Set-up' menu.
  - 'Voltage set-up'
  - Click on the New button.
  - Set the Timespan to 60 seconds.

Set up the experiment and do a test run
Assemble the circuit containing a simple resistor and connect the sensors as shown. Slowly adjust the variable resistor so that the voltage increases up to the maximum you want to use. If the graph is too large or too small to fit on the axes, adjust the limits by stretching or squeezing the scales.

Start collecting readings, gradually increasing the voltage at first and then decreasing the voltage.
Current and Voltage

Looking at Data

See the Skills Card for more details on using Datalogging Insight.

Take readings from your graph
What were the maximum readings for the voltage and current?
Did they reach maximum at the same or different times?

Replay the events of the experiment
- Check that the ‘Bars’ window is showing and move the cursor across the graph.

How does the variation in voltage compare with the variation of current?

Look for a pattern between voltage and current
- Plot a graph of current (Y axis) against voltage (X axis).

How would you describe the way in which the current changes with voltage?

Ohm’s Law says that for some conductors the current increases in proportion to the voltage.

Does your resistor obey this law? Explain your thinking.

Comparing two resistors
Now do a similar experiment with a different resistor and look out for similarities and differences. If you want to keep the first set of results on the screen, select ‘Overlay’ from the ‘Set up’ menu before you collect another set of results.

For further experiments, try combining two similar resistors in series or in parallel. Compare the results and decide what they tell you about how much current flows in each circuit.

What conclusions can you draw about the effects of combining resistors?

Comparing different components
This type of experiment can be used to find out the electrical properties of a range of different components. Try it with a torch bulb and notice how the graph depends upon whether you are increasing or decreasing the voltage. Try also diodes and LEDs for some surprises.
Find out about the ‘resistance’

- Click on the Formula button. Build the formula ‘A = V / I’ for the new set of data ‘A’. Click OK.

The new graph line ‘A’ shows the calculations of resistance for each pair of voltage and current readings.

You can rename the new channel ‘Resistance’ and alter the symbol to ‘R’ as follows:

- RIGHT click on ‘A’ on the Control Panel and select ‘Edit...’.

How did the resistance vary with the voltage and current?

Repeat this for different resistors and combinations of resistors.

What can you learn from comparing the graphs?

Find out about electrical power

Components carrying a current convert electrical power. You calculate power by multiplying the voltage by the current. To find out how much power was used in the circuit, create a new set of data as follows:

- Click on the Formula button and select ‘New’
- Build the formula ‘A = V * I’ for the new set of data ‘A’.
- Click OK.

The new graph line ‘A’ shows the calculations of power for each pair of voltage and current readings.

You can rename the new channel ‘Power’ and alter the symbol to ‘P’ as follows:

- RIGHT click on ‘A’ on the Control Panel and select ‘Edit...’.

How does the power vary with voltage and current?

Investigate the shape of the graph using ‘Change’ and ‘Interval’ on the ‘Analyse’ menu.
**Teacher's notes**

**Summary of the ideas here**

With Datalogging Insight it is possible to record a much larger number of readings than with conventional meters. This provides the opportunity to view ‘continuous’ graphs containing much more detail than is normal. It is useful to start with showing both voltage and current against time, to indicate how voltage and current increase or decrease together. It does not matter how steady or unsteady the changes are, the graph against time shows that they synchronise with each other. The ‘Bar display’ reinforces this when the cursor is swept across the graph.

The current-voltage graph shows the more traditional view of the relationship. Students can be asked to reason how the slope of the graph indicates how good the resistor is at conducting current. Different resistors and combinations of resistors are usefully compared by looking at the slopes.

The ‘Change’ and ‘Interval’ features can be used together to explore how equal changes of voltage cause equal changes in current when the resistor obeys Ohm’s Law. Non-Ohmic behaviour can be illustrated with diodes and torch bulbs which produce thought-provoking graphs. Rectifying diodes can take about 1A, but when using signal diodes and LEDs you need to take care that the current does not exceed a safe maximum of 20mA or so. The bulb shows the interesting effects of temperature change which depend on both the rate of increase of voltage and the direction of change.

**Programme of study keywords**

Simple measurements of current and voltage, how current varies with voltage in a range of devices.

**Data-logging skill level: medium**

The activity provides a general format for investigating the electrical characteristics of a variety of components.

**You will need**

Variable Resistor
Resistors (10 ohm, 20 ohm etc.)
Torch bulb, diodes, LED
Voltage and current sensors
Connecting leads and component holders
Battery with variable resistor for control
Interface, interface cable
Datalogging Insight software and computer

**Hints and tips**

Check that the voltage of the battery is compatible with the components and sensors. When using diodes, take particular care to limit the voltage and current.

This experiment is featured in Insight Laboratory. (Windows version only)
When you heat the air in a sealed container, the pressure inside increases and the container may even explode. How the pressure and temperature of a gas are related is of wide importance, for example in drink cans, refrigeration and the chemical industry.

In this activity you will see how temperature and pressure are related on a graph.

Set up the system
Connect the pressure and temperature sensors to the interface. Connect the interface to the computer.

Set up the Datalogging Insight software
• Open the Set-up file: OR
  'Pressure set-up'
• Select 'Sensing' from the 'Set-up' menu.
• Click on the New button.
• Set the Timespan to 20 minutes.

Set up the experiment and do a quick test
Assemble the equipment as shown.
• Click on the START button and take readings for a few moments.
You should see graph lines for pressure and temperature.
• Bend the pressure tubing, and warm the temperature probe in your hand.
• Click on STOP.

Does the screen show a change in pressure and temperature?
If not, check your settings and connections. You may also need to adjust the range on your sensors. If so, be sure to click on 'New'. Then do another quick test.

The experiment
Now do an experiment to find out how pressure changes with temperature.
• Place the flask in a hot water bath and watch the pressure and temperature as the flask warms.
• Click on STOP when the temperature has reached its maximum value.
• Click on START to record a further set of results for detailed study as the temperature falls.
Looking at Data

See the Skills Card for more details on using Datalogging Insight.

Replay the events of the experiment
- Check that the 'Bars' window is showing and move the cursor across the graph.

How did the pressure change over time?
How did the temperature change over time?
Is there any connection between what one or the other does?

See how pressure is related to temperature
You will now plot pressure on the vertical axis against temperature on the horizontal axis.
- RIGHT click on the vertical axis scale and select 'Pressure' from the list of channels.
- RIGHT click on the horizontal axis scale and select 'Temperature' from the list of channels.

If the replotted points appear to be in a line, this suggests a relationship between pressure and temperature.

Does the 'line' of points go through the origin?
What does this tell you?

Find out what sort of line fits the graph
- Select 'Zone' from the 'View' menu and click and drag the mouse to draw a Zone box to fit round the points on the graph.
- Click on the Trial fit button to show the dialogue box:
- Click on the channel button so that it reads 'Fit to P'.
- Click on 'Plot' and each formula in turn to see which give the best fit to the 'P' graph. This is usually a straight line.

Tick the 'Extrapolate' box and plot the fitted curve again.
Alter the limits for the temperature axis from -300 to 100 Celsius. This will enable you to see where the fitted line cuts the Temperature axis.

At what temperature does the extrapolated line indicate that the pressure would become zero?
What would you expect to happen to the air at this temperature?
Further Work

Change the temperature measurements so that they are in degrees absolute
To do this you need to add 273 degrees to the temperature measurements.

- Click on the Formula button and select 'New'
- Build the formula 'A = T + 273' for the new set of data 'A'.
- Click OK.

The new graph line 'A' shows the temperature measurements in degrees absolute.

You can rename the new channel 'Absolute temperature' as follows:
RIGHT click on 'A' on the Control Panel and select 'Edit...'.

See how the pressure is related to absolute temperature
You now need to make the graph show Pressure vs. Absolute Temperature:
- RIGHT click on the horizontal axis scale and select 'Absolute Temperature' from the list of channels.
- Rescale the temperature axis limits so that they show from 0 to 400.
Teacher's notes

Summary of the ideas here

With Datalogging Insight software, it is possible to record two sets of readings of pressure and temperature at the same time. You can change the axes to find the relationship between them, and the value of absolute zero - the intercept. You can also plot the pressure and temperature against each other as the experiment proceeds if you wish.

Programme of study keywords
Planning experiments, obtaining and analysing evidence.

Data-logging skill level: medium/expert
The skills required here involve using the 'Bar' window, trying to fit a formula to the graph and defining a new graph (plotting a YX graph using pressure and temperature, as opposed to a YT graph where they are plotted against time).

You will need
Pressure sensor and temperature sensor
Flask with bung, delivery tube and pressure tube
Water bath
Interface, interface cable
Datalogging Insight software and computer

Hints and tips
For best results fix the temperature probe in the centre of the pressure flask and allow the flask to cool very slowly, remaining immersed in the water bath.

Adequate results can be obtained over the temperature range 0 - 100 deg C, but, if a thermocouple probe is available, a larger temperature range is possible, making the extrapolation more reliable. In the latter case, the probe could be placed in a boiling tube with a tight-fitting rubber bung; the tube can be heated with a bunsen burner up to about 300 deg C and measurements recorded as it cools down in the air over a period of 10 minutes or so.

A number of factors need to be borne in mind when evaluating the results: the poor thermal conductivity of the air and the glass container; the time for the temperature probe to respond to temperature changes; the effect of convection in the flask.
A special property of a radioactive substance is that it is continually decaying. It gives off invisible radiations which can be detected by a Geiger-Muller counter. The readings give information about the rate of decay and the half life of the substance.

In this activity, you will use the computer to study a radioactive substance and measure its half life.

**Set up the system**
Connect a radiation detector, such as a Geiger Muller tube, to the interface.

**Set up the Datalogging Insight software**
- Open the Set-up file: 'Radioactive set-up'
- OR
- Select 'Sensing' from the 'Set-up' menu.
- Click on the New button.
- Set the Timespan to 10 minutes.

**Set up the experiment and do a test run**
Assemble the equipment as shown.

You will use the radioactive substance protoactinium in a liquid form in a tube.

- Place the tube in a vertical position.
- Clamp the detector as close as possible above the tube so that it can record the count rate from the top layer of liquid.
- Record the count rate for several minutes. Then measure the average count rate using 'Average' on the 'Analyse' menu and write this down.

When you are ready to start, shake the tube for three seconds and replace it underneath the detector.

- Click on START and observe the pattern of results on the graph.
Looking at Data

See the Skills Card for more details on using *Datalogging Insight*.

Replay the events of the experiment
Check that the 'Bars' window is showing and move the cursor across the graph.

*How steady were the results during the experiment?*

Describe the overall trend.

Make a smoother graph line
Creating a smoother version of the results makes it easier to see the trend.

- Select 'Smooth' from the 'Data' menu. In the 'Smooth' dialogue box, select the channel which you want to smooth.
- Click on 'Plot' to show the smooth line. If you want a smoother line, click on 'Plot' again.

*Does this show the trend in the results any better? Explain why.*

See if a curve fits your graph
- Select 'Zone' from the 'View' menu and click and drag the mouse to draw a Zone box to fit round the points on the graph, omitting the small readings towards the end of the experiment.
- Click on the Trial fit button to show the dialogue box.
- Click the channel button so that it reads 'Fit to C'.
- Click on 'Plot' and each formula in turn to see which give the best fit to your graph. This is usually an exponential curve.

When you are satisfied with the line, click on STORE; the line of best fit data will be stored as a new channel.

Find out about the rate of decay
Use the curve you have just fitted to your results to study how the rate of decay of the radioactive substance changed during the experiment.

- Select 'Rate' from the 'Analyse' menu. Move the cursor so that the vertical line is on a high part of the curve.
- Double click the mouse button. This should fix the line at that spot. As you move the cursor a little to the right, the control panel shows how quickly the count rate is reducing.

Repeat this for different starting points on the curve and look for a regular pattern.

*What happens to the rate of decay as the experiment proceeds?*
Further Work

Allowing for the background count

The detector should be as close as possible to the top of the tube so that it can detect the radiation from the radioactive substance dissolved in the upper layer of liquid. However, some radiation from the lower part of the tube and from the general surroundings is bound to be also picked up by the detector. To correct for this on the graph, you can calculate a new set of data by subtracting the general background value (which you recorded at the very beginning of the experiment) from the results. In the example here, the background count was 5.6.

- Click on the Formula button
- Build the formula 'A = C - 5.6' for the new set of data 'A'. Click OK.

The new graph line 'A' shows the corrected count rate.

Find the half life of the active substance

Use 'Trial fit' to plot a smooth curve which shows the underlying trend in the results.

Which type of curve best fits the results?

What are the properties of this curve shape?

Use this curve to find the half life of the substance as follows:

- Select 'Ratio' and 'Interval' from the 'Analyse' menu. Move the cursor so that the vertical line is on a high part of the curve.
- Double click the mouse button. This should fix a line at that spot. As you move the cursor to the right, the ratio between values shows on the control panel.
- Adjust the cursor until the ratio shows '0.50'. The time interval then gives the half life of the active substance.
- Double click to fix a line at a different point on the curve so that you can repeat this again.

What is the half-life? Do you need to take an average of several values?

Why is it better to use the fitted curve than the actual results for finding the half life?
Summary of the ideas here
This is an adaptation of the traditional experiment to find the half life of protoactinium. The latter is a daughter isotope from the decay of Thorium in the series:

\[
\text{U}_{238} \rightarrow \text{Th}_{234} \rightarrow \text{Pa}_{234} \rightarrow \text{U}_{234}
\]

Protoactinium decays giving out beta particles which can be detected using a Geiger-Muller tube. The source consists of a tube containing an aqueous solution of uranyl nitrate and an organic solvent. The decay of protoactinium can be detected in the organic layer in which it is soluble.

Datalogging Insight has a number of features which simplify the collection and analysis of the count rate from the detector. The graph display shows the random nature of the decay, but the underlying exponential trend can be identified using ‘Trial fit’. ‘Formula’ is useful for subtracting the background count rate and ‘Ratio’ makes it easy to measure the half life anywhere on the graph.

Programme of study keywords
Radioactive decay, half-life.

Data-loggting skill level: medium/expert
The activity runs through the skills in using features, such as ‘Rate’, ‘Define’ and ‘Trial fit’, required to analyse the results.

You will need
- Protoactinium source
- Clamp stand
- Geiger-Muller detector
- Interface, interface cable
- Data logging Insight software and computer

Hints and tips
Instructions for preparing the protoactinium source are as follows:

Required: One small polypropylene bottle (30ml), uranyl nitrate, concentrated hydrochloric acid, and amyl acetate or iso-butyl methyl ketone.

Preparation: 1g of uranyl nitrate is dissolved in 3cm³ of water and washed into a small separating funnel with 7cm³ of concentrated hydrochloric acid. To this solution, 10cm³ of amyl acetate or iso-butyl methyl ketone and the whole is shaken together for about five minutes. The liquid is then run into the polypropylene bottle and the cap firmly screwed on.

This experiment is featured in Insight Laboratory. (Windows version only)
Some chemical reactions are faster than others and one of the factors which affects this is the concentration of the chemical solutions being mixed.

Take the reaction between sodium thiosulphate and acid: When you mix the two solutions they form a precipitate of sulphur. If you use more concentrated solutions, this happens more quickly.

You can measure how quickly this happens by using a light sensor connected to a computer. You may be able to see if there is a pattern between how fast the reaction goes and the concentration.

---

**Set up the system**

Connect the light sensor to the interface.

**Set up the Datalogging Insight software**

- Open the 'Reaction set-up' file:
- OR
- Select 'Sensing' from the 'Set-up' menu.
- Click on the New button.
- Set the Timespan to 10 minutes.

**Set up the experiment and do a test run**

Assemble the equipment as shown.

- Place 50cm$^3$ of sodium thiosulphate in a beaker arranged as shown in the diagram.
- Click on the START button and squirt 5cm$^3$ acid into the flask. (The squirt action usually gives a good stir). Watch the trace on the computer screen as the reactants form a precipitate.
- Click on STOP when there is no further change.

*Does the graph show the change well?*

*Has the timespan been set adequately?*

**The experiment**

Now think about the experiments you will do to show how concentration affects the reaction. An easy way of varying the concentration is to dilute the sodium thiosulphate solution. You will need to do about 4 different experiments at 4 different dilutions.

Between each of your experiments you should save your results on the disk so that you have a series of graphs. You may also put the graphs on the same axis as you do the experiments. You do this by first selecting 'Overlay' from the 'Set up' menu. Each time you click on START to do a new experiment, a graph will be added to the ones already on the screen.
Looking at Data

See the Skills Card for more details on using Datalogging Insight.

Replay the events of the experiment
How did the graph change over time?
Write a sentence saying what was happening and why the graph went up or down.

Look at just one of your graphs
Decide which one of your graphs you will measure.
- Click on the letter buttons in the control panel until just that graph is showing on the screen.

Make a smoother graph line
- Click and drag the mouse to draw a box over the part of the graph where the change occurs.
- Use the 'Smooth' feature on the 'Data' menu if the graph line is 'noisy'.

Find out how long it took for a change to show
- Select 'Interval' from the 'Analyse' menu.
- Move to the point on the graph which shows when the acid was added. Double click the mouse. Then move the cursor to the point where the change just begins to show and note the 'Interval' time.

Find out how big the change was
- Select 'Change' and 'Interval' from the 'Analyse' menu.
- Move to the point where the change just begins to show and double click the left mouse button.
- Move the mouse to the end of the reaction and note the 'Change' shown in the Control Panel.
- Now move the cursor back to the point where the change is only half that noted at the end of the reaction.
- Record the 'Interval' time for the 'half change'.
- Repeat this for each of your graphs.

Find out the rate of change
- Select 'Gradient' from the 'Analyse' menu.
- Move the cursor across the graph and note the maximum gradient on the steep part of the graph.
- Repeat this for each of your graphs.

How does the rate of change depend upon the dilution of the sodium thiosulphate?
You will have to decide on the best method of taking information from the graph to make this comparison.
**Further Work**

**Prepare for a table spreadsheet to summarise your results**
- Make sure that you have saved all the data collected in your experiment on to a disk.
- Select 'Modelling' from the 'Set-up' menu.
- Click on the New button.
- Close the 'Model window' and display the 'Table window' instead.

**Build the table**
- Click the New Column button and add to the table a 'Value' column with the name 'concentration' and units '％'.
- Repeat this to create three more columns named 'time to start' (units 'seconds'), 'half reaction time' (units 'seconds') and 'maximum gradient'.

<table>
<thead>
<tr>
<th>Item</th>
<th>Graph</th>
<th>Concentration</th>
<th>Time to start</th>
<th>Time for half change</th>
<th>Maximum gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 A</td>
<td></td>
<td>20</td>
<td></td>
<td></td>
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<tr>
<td>1 B</td>
<td></td>
<td>40</td>
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<tr>
<td>2 C</td>
<td></td>
<td>60</td>
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<tr>
<td>3 D</td>
<td></td>
<td>80</td>
<td></td>
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</tr>
<tr>
<td>4 E</td>
<td></td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Click the New Row button a few times and enter the values obtained from your experiment.

**Plot your results on a graph**
The graph allows you to compare all your results and look for a pattern.
- Click the Graph button on the toolbar.
- RIGHT click on the horizontal axis scale and select 'Concentration' from the list of channels.

*What does the shape of each graph line tell you about the rate of the reaction?*

**Find out what sort of line fits the graph**
- Click on the Trial fit button and experiment to find a line which fits the graph.
Summary of the ideas here
The light sensor can be used like a colorimeter to follow a precipitation reaction. The reaction is repeated at different concentrations, and Datalogging Insight allows you to record each of these reactions. The software allows you to measure the gradient of each graph, or the 'rate of reaction' for each concentration.

Programme of study keywords
Rates of reactions, planning experiments, obtaining and analysing evidence.

Data-logging skill level: expert
The skills required here involve using the Overlay feature where successive experiments are built up on the same axes. Using the 'Bar' window replays the events of the experiment, while 'Smooth' removes 'noise' from a graph line. To show the rate of reaction you record the change in a certain time interval.

You will need
- 100cm³ beakers
- 50cm³ measuring cylinder
- 5cm³ syringe
- 50cm³ 1M hydrochloric acid
- 250cm³ 1M sodium thiosulphate solution
- Distilled water
- Clamp stand, clamps and lamp
- Light sensor
- Interface, interface cable
- Datalogging Insight software and computer

Hints and tips
Wash the reaction vessel soon after each experiment as the precipitated sulphur does not always rinse away easily.

Some technical skill is required to control and perform this series of reaction rate experiments. It is therefore recommended that you save the results between each experiment. If there is an error, you will be able to recover easily by going back, opening the last saved file, and repeating the last experiment.
Pendulum Motion

A pendulum is a device that can be used to help clocks keep time. If you were stuck on a desert island, and you needed to make a clock, it would help to know about pendulums.

For example, do you know whether the time for a swing depends on the size of the swing? And how the pendulum changes its speed during a swing?

You can begin to understand pendulums by using one connected to the computer. Remember that the time for one complete swing of a pendulum, there and back, is called a 'period'; also, that the size of a swing is called the 'amplitude'.

Set up the system
Connect the position sensor to the interface.

Set up the Datalogging Insight software
- Open the Set-up file: 'Pendulum set-up'
- Select 'Sensing' from the 'Set-up' menu.
- Click on the New button.
- Set the Timespan to 20 seconds.

Set the scale for the Y axis
- Select 'Calibration' from the 'Set-up' menu.
Look at the Signal level gauge and rotate the barrel of the position sensor so that the resting position of the pendulum reads about 50%.
- Click on the < button to define the 'Low' signal level, making the physical value '0'.
- Hold the pendulum at an angle of about 20 degrees to vertical.
- Click on the < button to define the 'High' signal level, making the physical value '20'. Then set the axes limits to 'Upper: 20' and 'Lower: -20' and click on OK.
- Finally, if you prefer to have the X-axis halfway up the screen, select 'Axes' from the 'View' menu and choose the second axes format. Click on OK.

Set up the experiment and do a first run
- Click on the START button, hold the pendulum and then release it to see how this is recorded on the graph: you will need to judge how far to swing the pendulum in your experiments.

Make a recording of a medium size swing of the pendulum. Then decide if you need to adjust the axis, the timespan or the sensor.
Looking at Data

See the Skills Card for more details on using Datalogging Insight.

Replay the events of the experiment
Check that the 'Bars' window is showing and move the cursor across the graph.

Looking at your graph, how can you tell when the pendulum is at the mid-point of its swing?

Find out how long a change took to occur
Does the time interval change from peak to peak? Describe what you find.

Arrange to put all the graphs on the same axis
You will now see how different size swings affect the pendulum period.

• Select the 'Overlay' option on the 'Set-up' menu so that it appears with a tick.
Each time you collect more data, a graph will be added to the ones already on the screen.

Make the recording start at the beginning of the swing
• Select 'Condition' from the 'Set-up' menu.
In the dialogue box, select the button which gives a triggered start when the input 'rises through threshold'.

As soon as you click START the software will be ready to record your first experiment.
Each new set of results will fit neatly on top of the previous set.

Testing different swings
Now find how the size of the swing affects the time of the swing. Push the pendulum and the computer should record a swing.

To do your next experiment, just click on START again. Then repeat this using larger and larger swings.

What does this tell you about the usefulness of a pendulum to make a clock?
Summary of the ideas here
The position sensor provides some graphic evidence about the swing of a pendulum. It shows
the amplitude and the time period very clearly and such measurements can be taken from the
graph. You can also derive or calculate new graphs showing the velocity or acceleration of the
pendulum.

In this activity the students do a simple single experiment and then use the tools in the
Data logger Insight software to explore the data further.

You can also superimpose a succession of traces using different sizes of swing using the
'Overlay' and 'Trigger' (see 'Condition' on the 'Set up' menu) features of Data logger Insight.
The latter is like the trigger feature of an oscilloscope, and it allows you to initiate recording
at the same point of each trial swing.

Programme of study keywords
Planning experiments, obtaining and analysing evidence.

Data-logging skill level: expert
This activity involves the skills of overlaying graphs and starting a recording with a trigger
(Condition) feature.

You will need
Position sensor and pendulum
Interface, interface cable
Data login Insight software and computer

Hints and tips
It is worth spending a minute or two setting the system, as described, so that the pendulum
rest position is at zero.

Note that when you set the 'Trigger' (Condition) feature, it is only necessary to press the
green START button once. If you press it a second time, the condition will be released and the
recording will start as normal.

You may want to change the 'Trigger' setting or the direction from which you release the
pendulum.

You may extend the activity to show the effects of changing the mass of the pendulum. Or
show the effect of air damping, using a card stuck on the pendulum bob using Blutack.

The Model
When built, this model simply calculates sinusoidal data. As students experiment with
different values for amplitude and frequency, they soon learn how to adjust these parameters
to predict the shape of the graph. To keep the calculations simple, it is suggested that the
frequency is expressed in radians per second. A further formula (T = 2 * pi / w) and variable
'T' may be defined to calculate the 'period' of the pendulum which can be compared with a
direct measurement of the period from the graph.

This experiment is featured in Insight Laboratory. (Windows version only)
Further Work

Calculate angular velocity using your displacement readings
- Click on the Formula button and select 'New'. Build the formula 'B = dA/dt' for the new set of data 'B'.
- Click OK.

The new graph line 'B' shows the calculations of velocity against time.
You can rename the new channel 'Angular velocity' and alter the symbol to 'V' as follows:
RIGHT click on 'B' on the Control Panel and select 'Edit...'.

Explain the phase relationship between the displacement-time and velocity-time graphs.

Build a model to match your results
Your aim is now to build a model which will calculate data similar to that which you obtained in the experiment. Show the 'Model' window and define four blocks as follows:
• Define a constant named 'amplitude' with the symbol 'a'. (blue block)
• Define a constant named 'frequency' with the symbol 'w'. (blue block)
• Define a variable named 'data' with the symbol 'D'. (pink block)
• Define a formula which reads 'D = a * Sin(w * t)' (green block)

Experiment with the values of 'a' and 'w' to produce a sine wave which has the same appearance as the graph from your experiment. (Double click on the blue blocks to show the box for changing the values.)

How does the appearance of the graph change as you increase the amplitude 'a'? How does the appearance of the graph change as you increase the frequency 'w'?
On those hot summer days it would be nice if you could do something to make the heat more bearable. You could, for example, get your computer to switch on a fan when the room gets too hot.

But does the fan really make you any cooler? Using some sensors, a model fan and a control box you could try to find out.

Set up the system
Connect the sensors to the interface. Then connect a motor fan to a pair of output sockets on the control box. The control box is usually connected to the interface. Arrange for the fan to blow air over your temperature probes.

Set up the Datalogging Insight software
- Open the Set-up file: 'Control set-up'
- Select 'Sensing' from the 'Set-up' menu.
- Click on the New button.
- Set the Timespan to 5 minutes.

Set the temperature for turning on the fan
- Select 'Control' from the 'Set up' menu. Type in a temperature for switching on the fan; a few degrees above the temperature of the room is most suitable.
- Tick the 'Enable' box.

Set up the system and do a test run
- Click on START and switch on the lamp (heater).

Does the temperature change when the lamp is switched on? If not, arrange things so that it does.

When the temperature reaches the level you set, the 'fan' should switch on.

Start collecting data
- Click on START and switch on a lamp to warm both of your temperature probes.

When the temperature increases the fan will switch on.

What do you expect to happen to the temperature when the fan blows air over the dry temperature probe?

What would you expect to happen to the temperature when the fan blows air over a wet temperature probe?

Wet the cotton wool on the second probe to test your idea.
Looking at Data

See the Skills Card for more details on using Datalogging Insight.

Replay the events of the experiment
- Check that the 'Bars' window is showing and move the cursor across the graph.

How did the fan affect the temperature of the probes during the experiment?

Find out how much the temperature changed

How much did the temperature change on the dry temperature probe?
How much did the temperature change on the wet temperature probe?

What does this tell you?
**Looking at a Model**

- Open the *Datalogging Insight* file 'control model'.

The model calculates the temperature of a measuring probe fitted with a moistened ball of cotton wool. The calculations predict the cooling effect when the fan is switched on.

- Click on START to run the model.

Notice how the graph shows when the fan is switched on; the table shows a 'Fan' column containing '1' when the fan is on and '0' when the fan is off.

**Explain why the temperature sensor cools when the fan is on.**

- Select 'Average' on the 'Analyse' menu and find the average temperature while the fan is on.

In the table, type in some more values of '1' in the 'Fan' column. This has the effect of switching the fan on for a longer period of time.

**What is the effect on the average temperature of switching the fan on for longer?**

Here are a number of further investigations to try:

1. Experiment with switching the fan on for a period and off for a period.
2. Find out how varying the on/off periods affect the average temperature.
3. Find out how effective the cooling is for different room temperatures.
4. Find out the effect of altering the values of the warming and cooling constants.

\[
\Delta T = (WC \times (Tr - T) - CC \times F) \times \Delta t
\]
**Teacher’s notes**

**Summary of the ideas here**

*Datalogging Insight* can display information from temperature probes over time. The software also has a control feature which allows you to control an output from a control box. The output can power a motor or model fan and make a useful monitoring and control system. This activity tries to encourage discussion on a common notion - that a fan blows cold air.

**Programme of study keywords**

Changes of state, evaporation, monitoring and control.

**Data-logging skill level: medium**

This activity requires just the basic idea of using a data-logging system. To use the control feature you will also need to find out how to connect the system together.

**You will need**

- Heat source such as an angle-poise lamp
- Clamp stands to hold the temperature probes
- Cotton wool and elastic band
- Motor unit with propeller blade for the fan
- Control box
- Interface, interface cable
- Two temperature sensors.

*Datalogging Insight* software and computer

For the extra heating activity: Low current heater circuit and a relay

**Hints and tips**

Check the detail of your data-logging interface manual to find out where you connect a control box. Some interfaces have a built-in control unit, most require you to connect an external one.

Many school technology departments have a control box that you may be able to connect to your data-logging interface.

A relay and fan circuit connected in place of the motor unit will allow you to use a more powerful fan. If you have a mains control unit, which some manufacturers supply, you will be able to power a genuine desk fan from your data-logging system.

Be prepared to repeat the experiment with the system to get the optimum conditions.

You can also do this activity using a single temperature probe.

**The model**

The model calculates the temperature of the sensor which cools due to evaporation of moisture in the cotton wool. The main purpose of the model is to explore the effect of convection when the fan is switched on. The model takes into account the cooling due to evaporation and the warming due to the transfer of heat from the surroundings.

The main assumption of the model is that evaporation mainly occurs while the fan is switched on. In order to keep the model simple, the ‘cooling constant’ incorporates several factors including latent heat of vaporisation, thermal capacity of the probe and the quantity of moisture present. Similarly, the ‘warming constant’ attempts to summarise contributions to the thermal capacity of the system which determine the rate at which thermal equilibrium is re-established.

By typing in noughts or ones in the ‘Fan’ column, students have direct control over when the fan is switched on, unlike when the computer takes control as in the main activity. A stronger fan may be simulated by typing larger values in the ‘Fan’ column!
In this activity you will try to measure the reaction times of your group. But, like many measurements you make in science, you will need to work carefully and repeat your results until you can be sure they are reliable.

Drivers need fast reactions to events. For most adults, it takes just over half a second (0.6 sec) to react. So if you can react faster, you can brake or steer sooner and avoid a problem.

Set up the system
Connect your switch-type sensors to the interface.

Set up the Datalogging Insight software
- Open the Set-up file: OR Select 'Timing' from the 'Set-up' menu.
  'Time set-up'
  - Click on the New button.
  - Display the Chart window.
  - Adjust the measurement boxes to read 'Time from A to B'.

Do some test runs
Make sure that you can see the signal lights 'A' and 'B' on the Control Panel.
- Select 'Snapshot' from the 'Collect' menu.
- Get student A to trigger sensor A. Student B must then trigger sensor B as quickly as possible.
- For another go, click on RESET (student C). If preferred, the SPACE bar on the keyboard may be pressed instead of using the mouse.

If you need to rub out a result click once on the Delete button.

Experiment
You need to click on RESET or press the SPACE bar before each test. Here are three experiments to try. Try to practise each one until you can get a few similar results in a row. Measure how long it takes for you to react...

1. When you can see the student triggering sensor A.
2. When you can see the signal from sensor A change on the screen.
3. When you can hear the student triggering sensor A.

Find out how many practice runs are needed before the results settle down to similar values.
Looking at Data

See the Skills Card for more details on using Data Logging Insight.

Look at the Bar chart and table

Do you react faster when you watch the sensor or when you watch the screen?

Do you react faster to a sound?

How do the reaction times of members of your group differ?

How many ‘practice goes’ seem to make a difference?

Were you able to get three or four similar results in a row? If not, can you say why.

• Add student names to the table

• Click the New Column button and add to the table a ‘Text’ column with the name ‘Name’. Use this column to enter a student name for each line of data. You can highlight particular rows of data by clicking or dragging the mouse in the ‘Item’ column.

Calculate average times

You may have a large table of results belonging to different experiments and several students. It is useful to calculate an average time for a group of results.

• Click the New Column button and add to the table an ‘Average’ column.

• Click on the heading of the results column ‘Time AB’ so that the whole column is highlighted.

• Choose a group of results for which you want to find an average and click in the ‘Averages’ column in the bottom row for the group. Repeat this for other groups.

What can you learn from the average values?

Further Work

Do people react faster or slower when they use their feet instead of their hands?

Is the reaction time the same for different people? Do you improve after a cup of coffee, tea, or can of coke?

Get a copy of the ‘Highway Code’. Look up how far a car at 30 mph travels whilst the driver is reacting. Calculate the stopping distance at this speed.
Looking at a Model

- Open the Datalogging Insight file 'braking model'.

The model calculates the total stopping distance needed by a car when the brakes are applied. The calculations are based on information you supply about the speed of the car and the driver's reaction time.

- Click on START to use the model.

- Click on the block 'S1' showing speed in m.p.h. and adjust the value to read 5 m.p.h.

- Click on STORE to record the calculation in the table.

- Repeat this for other values of the speed, increasing it by 5 m.p.h. each time.

- Highlight the 'total stopping distance' column and click on the Chart button.

Looking at the bar chart, describe how the required stopping distance changes as the speed of the car increases.

Look carefully at the model to find out the purpose of each formula.

- Plot bar charts of two other columns in the table; the 'thinking distances' and the 'braking distances'.

What are the similarities and differences between these two charts?

Now look at the 'reaction time' variable. In practice, the value for this depends upon the driver's state of alertness which is strongly influenced by time of day, tiredness and previous use of alcohol.

- Try increasing the value for reaction time and observe the effect on the 'stopping distance' for a particular speed.

What happens to the total stopping distance if the driver's reaction time is longer?

Which other variables in the model are affected by the reaction time?

- Plan how you might develop the model to predict how the amount of friction between the tyre and the road affects the 'braking distance'. You will need to add another variable to represent the friction. Think about how rain on the road affects tyre friction.
**Teacher's notes**

Summary of the ideas here

*Datalogging Insight* software and switch-type sensors allow you to time events with great accuracy. This activity is one the students will relate to easily as they can get used to the software.

**Programme of study keywords**

Nervous system, determining time, planning experiments, obtaining and analysing evidence.

**Data-logging skill level: beginner**

The activity requires the skills of choosing the measurement settings, of collecting results into a table and of averaging sets of results.

**You will need**

Two switch-type sensors such as: light gates, light switches, push-switches, timing pads

Interface and interface cable

*Datalogging Insight* software and computer

**Hints and tips**

If students click on STOP but later want to collect more results, they need to go to the 'Collect' menu and select 'Snapshot' again. When it is time to clear all the results, go to the 'Edit' menu and select 'Delete all data'.

**The Model**

The model calculates several variables which influence the minimum braking distance of a car:

Thinking distance: the distance travelled during the time taken by the driver to react to the need to apply the brakes

Braking distance: the distance travelled whilst the brakes are actually applied

Total stopping distance: the sum of the distances involved.

The model is used in 'Free' mode which allows pupils to adjust the input variables (speed and reaction time) and directly observe the calculated result. Each calculation may be inserted into the table by a single click on STORE (or a press of the SPACE bar). With such a small number of results involved, the bar chart provides a useful graphic display. These reveal the linear dependence of the thinking distance on the speed and the squared dependence of braking distance on speed. These relationships are a consequence of the assumptions in the model:

1. The thinking distance depends linearly on the speed.
2. The braking distance depends upon the kinetic energy.

Further discussion can focus on the validity of these assumptions and what other variables might be considered in an improved model. For example, in the formula for braking distance, the value '14' may be replaced by a friction variable.
At a local model car club, the members argue too much about who's electric car is the fastest. Their stop-watches cannot measure the speeds accurately enough. By using the computer you can gain great accuracy. In this activity you will learn how you can measure the speed of a model car in two different ways.

Set up the system
Connect your switch-type sensors to the interface.

Set up the Datalogging Insight software
- Open the Set-up file: "Speed set-up"  
- Select ‘Timing’ from the ‘Set-up’ menu.  
- Click on the New button.  
- Display the Chart window.  
- Adjust the measurement boxes to read ‘speed from A to B’.

Do a test run
Find out which sensor is A and which is sensor B. Clamp the sensors into place about 0.5 to 1 metre away from each other on a level bench. Measure the distance between the two sensors.  
- Click on START.
When the ‘Parameters’ box appears, enter the distance (in cm.) between the sensors. Click on OK.
Switch on the model car so that it runs past sensor A and then past sensor B. You should see the car’s average speed in the Table window and the Bar chart. If not try again or check the details above.
Remember that the computer calculates the average speed for each run because it uses the total distance and the total time to travel from A to B. It cannot detect any variations during each run.

Investigate the average speed of cars
Run the first model car past sensor A and then past sensor B. Do this a few times and see if you can get a consistent answer. Now test another car.

If you need to rub out a result
- Click once on the Delete button.
When you want to clear all the results, go to the ‘Edit’ menu and select ‘Delete all data’.
Looking at Data

See the Skills Card for more details on using Datalogging Insight.

Find out how the results vary
If you measured the distance in cm and the time in seconds, what are the units for speed?

Explain why you were, or were not able to get the same answer for the speed each time; what factors do you need to consider?

Do you think your car's speed increased, decreased or stayed the same as it went from one sensor to the other?

Find an average of the results
You can find an average of a group of results on the chart as follows:

- Select 'Average' from the 'Analyse' menu.
- Decide which group of results you want to find an average for.
- Double click on the first bar in the group.
- Move the mouse to point to the last bar in the group. The average value shows in the Control Panel.

Which car had the highest average speed?

How could you compare the speed of different cars fairly?

Extra

How does the slope of the surface affect the average speed?

How does the type of surface affect the average speed?

Does a heavier car run downhill faster?

For a clockwork car, how does the amount of winding up affect the average speed?
Further Work

Find how the speed of a car changes as it travels
When your car moved from A to B its speed was changing. If it was slowing down, its speed at A was faster than it was at B. In this section, you will measure the speed of your car at A and then again at B.

- Select the measurement options on the Control Panel so that they read 'Speed at A then B'.
- Click on START. When the 'Parameters' box appears, enter the length of the interrupt card.

Experiment
- Measure the speed of your card as you run it past sensor A and then past sensor B. See if you can repeat your results.
- Test another car.

The computer measures how long the card took to pass a sensor. To work out the speed, it uses the time taken for the card to pass the sensor. It then divides the distance travelled (the card length) by how long the card took to pass the sensor.

- Look at the speeds, at A then at B. Are your cars speeding up or slowing down?

Can you explain your answer?

You can calculate the rate of change of speed by adding another column to your table of results:
- Click on the New column button on the toolbar.
- Click on 'Formula' and type the heading ‘Rate of change’ (acceleration). Then use the dialogue box to create the formula ‘(Speed B - Speed A) / Time AB’.

What are the similarities and differences between the values in this new column?
Teacher’s notes

Summary of the ideas here

Datalogging Insight software and switch-type sensors allow you to measure time and calculate speeds in two different ways. In the first, the time for a car to pass from one sensor to the next is measured and then divided by the distance travelled to provide the average speed.

In the second, the speed of the car at each sensor is measured. The sensor records the time when the sensor beam is cut by the front and the rear edge of a card. It divides this into the length of the card. Two speeds are obtained, one at the first sensor, and one at the second.

Programme of study keywords

Determining time and speed, planning experiments, obtaining and analysing evidence.

Data-logging skill level: medium

Requires the skill of collecting results into a table.

You will need

- Two switch-type sensors such as light gates or light switches
- Clamps, Ruler
- Toy cars (battery or clockwork-driven)
- Interface and interface cable
- Datalogging Insight software and computer

Hints and tips

The distinction between the two methods of measurement in this activity needs explaining; ‘from A to B’ uses the time to travel the distance between the sensors; ‘at A then B’ uses the times for the car to pass each sensor. This may be easier to understand after the students have tried each method.

You can use pressure mats to measure average speeds if you tape two pressure mats to the floor and for example, ride a bicycle or hop from one to the other. Some light switches work better facing a light source, whereas some work better facing away. Fluorescent strip lighting can produce spurious results with some light switch designs.

The sensors and software use split second timing and tiny errors, such as a skewed movement of the card, tend to be exaggerated. The interrupt card should be coloured black, and have tidy parallel edges.

To adjust the number of decimal places shown in the results, double click on the column heading and select the new number.
Velocity in Free Fall

How does the velocity of an object change as it falls? Does it speed up? How does its speed depend upon the height it falls? Does it fall twice as fast if you drop it from twice the height?

In this experiment you can find out the answers by dropping a card through a light gate. You will need to measure the height fallen, but the computer calculates the velocity for you.

Set up the system
Connect a light-gate sensor to the interface.

Start the Datalogging Insight software
- Open the Set-up file: 'Velocity set-up'
- Select 'Timing' from the 'Set-up' menu.
- Click on the New button.
- Display the Chart window.

Experiment
- Clamp a ruler beside the sensor so that when the card drops, you can measure how far it falls.
- Draw a line half way across the card and measure the distance from the midpoint (rather than from the lower or upper edge) to the sensor.
- Click the New Column button and add to the table a 'Value' column with the name 'Height' and unit 'cm'.

You are trying to find out if there is a connection between the height the card falls and its velocity.
- Click on START. When the 'Parameters' box appears, enter the length of the card in cm.
- Drop your card from a measured height and record the velocity. On the same row in the table, enter the height in the 'Height' column: click on the cell and type your measurement in the box.

Try again to see if you can repeat your result.

Repeat the process several times, dropping the card from different heights. Try to change the height in steady steps.
Looking at Data

See the Skills Card for more details on using Datalogging Insight.

Looking at the results

Looking at your figures, how does the final velocity of the card vary with height?

Plot your results on a graph

The graph is a more precise tool for analysing the pattern in your results.

- Click the Graph button on the toolbar.
- RIGHT click on the vertical axis scale and select 'Velocity' from the list of channels.
- RIGHT click on the horizontal axis scale and select 'Height' from the list of channels.
- Click on the Smooth join button to draw a line through the points.

Describe the pattern in your results.

Calculate the averages of repeated results

If you repeated the measurements and have a series of results for each height, you can average each series in the table by creating a new column:

- Click the New Column button and add to the table an 'Averages' column with the name 'Average height' and unit 'cm'.
- Click on the heading of the results column 'Velocity' so that the whole column is highlighted.

Decide a group of results for which you want to find an average and click in the 'Average height' column in the bottom row for the group. Repeat this for other groups.
Further Work

Find out what sort of line fits the graph
- Click on the Trial fit button and experiment to see which type of line fits best.
- Click on 'Plot' to see the line. For a straight line, the gradient 'a' and the intercept 'c' are calculated for you in this box too.

Does the velocity increase linearly with height?

Calculate the velocity squared
- Click the New Column button and add to the table a 'Formula' column with the name 'Velocity squared'. Then use the Formula box to build the formula 'Velocity squared = Velocity A^2'.

- Plot a graph of velocity squared against height.
- RIGHT click on the vertical axis scale and select 'Velocity squared' from the list of channels.
- RIGHT click on the horizontal axis scale and select 'Height' from the list of channels.
- Click on the Trial fit button and experiment to see which type of line fits best; click on 'Plot' to see the line.

What conclusion can you draw about the relationship between velocity and height?
Teacher's notes

Summary of the ideas here
Switch-type sensors allow you to measure time and speed. Datalogging Insight software allows you to record your results in a special table where you can do calculations such as averages. You can also plot the columns in the table on a Y-X graph and create best-fit lines to your data.

Programme of study keywords
Determining time and speed, planning experiments, obtaining and analysing evidence.

Data-logging skill level: expert
The activity uses the skills of selecting the measurement settings and collecting results in a table. It also involves calculating averages, calculating velocity squared with a formula, plotting results on a Y-X graph and plotting a best-fit line.

You will need
Switch-type sensor such as a light gate or light switch
Black interrupt card - credit card size
Blutack, clamps and ruler
Interface and interface cable
Datalogging Insight software and computer

Hints and tips
Attach a blob of Blutack on each of the lower corners of the interrupt card. This lowers the centre of gravity and makes it more stable and less likely to wobble, rotate or flip during the fall. The card should also be firm, black, and have tidy parallel edges.

This experiment deliberately moves on from talking about 'speed', the focus of the previous experiment, to refer to 'velocity'. The difference between speed and velocity is really fudged by the measurement process since the action of the light gates and the calculations in the program are exactly the same. The distinguishing direction component for velocity is omitted in most numerical problems, unless opposite directions arise.

Some light switches work better facing a light source, whereas some work better facing away. Fluorescent strip lighting can produce spurious results with some light switch designs.

The number of decimal places shown in the results can be adjusted by selecting 'Units' from the 'Set-up' menu: Adjust any of the other measurement settings here as required.
Force and Acceleration

In this activity you will measure the acceleration of a trolley on a runway. The trolley is attached to a falling mass - making it accelerate. You will see the effect of different masses.

A specially cut interrupt card allows you to measure the acceleration of a trolley using only one sensor.

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**Set up the system**
Connect a light-gate sensor to the interface.

**Start the Datalogging Insight software**

- Open the Set-up file: 'Acceleration set-up'
- Select 'Timing' from the 'Set-up' menu.
- Click on the New button.
- Display the Chart window.
- At the top of the Control Panel, adjust the measurement boxes to read 'Acceleration at A'.

**Do a test run**

- Clamp the sensor into place over the runway. The runway should be fairly level. Fix the double interrupt card to the trolley. Click on START.
- When the 'Parameters' box appears enter the length of the card segment in cm into the Interrupt card box and click OK.

Allow the trolley to move past the sensor. The screen should show you a reading in the 'Table' window and in the 'Chart' window. If not try again or check the details above.

**Make a new column to record the force**

- Click the New Column button and add to the table a 'Value' column with the name 'Force' and unit 'newton'. (The force column is already prepared in the set-up file).

**Make your measurements**

For a 1kg trolley start with an hanging mass of 50g. Place the five spare remaining masses on the trolley. Click on START and allow the trolley and its card to roll past the sensor. Repeat this measurement 2 or 3 times.

Enter the force of gravity on the mass (i.e. 0.5 Newtons) alongside the results in the Force column: simply click on the appropriate cell in the table and type it in.

Repeat the trolley run using other masses: 100, 150, 200, 250, 300g. These provide forces of 1.0, 1.5, 2.0, 2.5, 3.0 N respectively. In other words, for each run you take a mass from the trolley and place it on the hanging mass - this is to keep the total accelerated mass constant.
Looking at Data

See the Skills Card for more details on using Datalogging Insight.

Looking at the results

Look at the bar chart: Is there a pattern between the force and the acceleration?

Plot your results on a graph

The graph is a more precise tool for analysing the pattern in your results.

- Click the Graph button on the toolbar.
- RIGHT click on the vertical axis scale and select 'Acceleration' from the list of channels.
- RIGHT click on the horizontal axis scale and select 'Force' from the list of channels.

Find out what sort of line fits the graph

- Click on the Trial fit button and experiment to see which type of curve fits best.
- Click on 'Plot' to see a best-fit line.

For a straight line, the gradient is calculated and shown as ‘a’. (The gradient should give the 1/total_mass)

Describe the connection between force and acceleration.

Calculate the averages of your repeated results

You can average the results of similar experiments in the table and plot these on the graph for comparison.

- Click the New Column button and add to the table an ‘Averages’ column with the name ‘Average acceleration’ and unit ‘cm/s²’.
- Click on the heading of the results column ‘Acceleration’ so that the whole column is highlighted.

For each group of results you want to find an average, click in the ‘Average acceleration’ column in the bottom row for the group. Repeat this for other groups.

In the graph window:

- RIGHT click on the vertical axis scale and select 'Average acceleration' from the list of channels.

How does the new graph compare with your Force and Acceleration graph?

Describe how you managed to control some of the variables in this experiment.
Which variables were more difficult to control?
Looking at a Model

- Open the Datalogging Insight file 'acceleration model'.

The model calculates the distance moved by an object which is made to accelerate by an applied force.

- Click on START to use the model.

Observe how the distance, velocity and acceleration vary while the model is running.

What are the differences between the three graphs?

- Click on the 'force' box and increase the start value. Observe the effect on the graphs.

- Click on the 'mass' box and increase the start value. Observe the effect on the graphs.

Explain how the graphs support the results you obtained in the experiment.

- Set the start values for force and mass to be the same as the values used in your experiment. Compare the acceleration calculated by the model with the measurements obtained in the experiment.

\[ a = \frac{F}{m} \]

\[ \Delta v = a \Delta t \]

\[ \Delta s = v \Delta t \]
Summary of the ideas here

Data logging software allows you to record your acceleration results in a table where you can add your own data as well as do calculations. You can also plot columns in the table on a Y-X graph and create best-fit lines for your data.

Programme of study keywords

Acceleration, planning experiments, obtaining and analysing evidence.

Data-logging skill level: expert

Requires the skill of collecting results into a table, plotting a graph as well as a best-fit line.

You will need

- A switch-type sensor such as a light gate or light switch
- Double-interrupt card - black
- Blutack
- Trolley and 300g slotted masses in steps of 50g
- Clamps, pulley, and string
- Ruler
- Interface and interface cable

Hints and tips

This experiment is not for novices; however, the bar chart gives a nice visual display of the acceleration doubling and trebling as the force is doubled and trebled.

It doesn't matter too much how level the table or track is. Usually you adjust the slope of the runway to compensate for friction. You can still do that, but experience shows that it does not spoil the linearity of the graph.

Careful friction-compensation helps the line pass through the origin, otherwise there will be an intercept with the acceleration axis. You should get an interesting spread of individual results but the trend is usually clearly linear.

The 'average acceleration against force' graph usually gives a cleaner plot - with many of the points going through a straight line. You can use this as a focus for discussion on experiment variables and sources of error.

The double interrupt card should be firm, black, and both segments should be equal in width. It should pass as close as possible to the light gate sensor.

The Model

The model calculates the distance moved, velocity and acceleration of an object caused to accelerate by a steady resultant force. Students can experiment with the input values of force and mass and observe the calculated motion parameters. The model calculates small increments in distance and velocity and automatically adds these together to display the accumulated value. In this way the model is able to handle situations where the initial values are not necessarily zero.
Building Bridges

Bridges have to carry huge loads - cars, lorries and more. Now and again you hear about a bridge disaster, so we don't always get things right.

Maybe we should make our bridges stronger? If we used more material the bridge would be stronger, but could we predict how strong a bridge will be without actually making it? In this activity you build some bridges and test them with weights. Then you can advise on how strong they should be made.

What to do
1. Use one piece of card to build a bridge to span a 15cm gap. A simple design with a triangular cross-section is best.
2. Test your bridge with weights to see how much it can take. Make sure you test your bridge scientifically.
3. You could make the same bridge using two, three, four and five pieces of card.
4. Make these bridges and test them with weights.

Record your results as described below.

Start the Datalogging Insight software
- Select 'Modelling' from the 'Set-up' menu.
- Click on the New button.
- Close the 'Model' window and open the 'Table' window.

Make a column to record how much card you used
- Click the New Column button and add to the table a 'Value' column with the name 'Card' and unit 'sheets'.
- Enter the numbers 1 to 5 down this column.

Make a column to record the weights held by the bridge
- Click the New Column button and add to the table a 'Value' column with the name 'Mass' and unit 'gram'.

Enter your results
- Click in the table cells to enter your results. You will not have any results for six or seven pieces of card.
Looking at Data

See the Skills Card for more details on using Datalogging Insight.

Find out if there is a pattern in the data

- Click on the Graph button on the toolbar.
- RIGHT click on the vertical axis scale and select 'Mass' from the list of channels.
- RIGHT click on the horizontal axis scale and select 'Card' from the list of channels.
- Click on the Smooth join button to draw a smooth line through all the points.

Results

How does using more material affect the strength of a bridge?

- Use Trial fit to find the best line which fits the data. Tick the 'Extrapolate' box so that the line extends beyond the largest value.
- Scroll the X axis of the graph so that you can read off a prediction of the mass which could be taken by a bridge made with 6 or 7 pieces of card.

How much mass would a bridge with six and seven pieces of card take?

- If you have time, make and test a bridge made with 6 or 7 pieces of card.

Does your graph over or underestimate the strength of these bridges?

Write a note to a bridge engineer. Describe your thoughts about using more material to build a bridge.
Summary of the ideas here

Datalogging Insight allows you to record the most basic experiment results in a table. You can draw graphs, and change the items you want to plot very easily. In this example, a graph is drawn and the results extrapolated to make a prediction.

Programme of study keywords

Forces, planning experiments, obtaining evidence, analysing evidence and drawing conclusions.

Data-logging skill level: beginner

The activity uses the skills of making your own table spreadsheet, entering your data as well calculating and plotting it on a graph.

You will need

- Tape
- Scissors
- Weights
- ‘Piers’
- Soft card
- Interface and interface cable
- Datalogging Insight software and computer

Hints and tips

The bridge design needs to be the same for each test; with thin card, a simple triangular cross-section design is effective. Alternatively, strips of corrugated card, cut parallel to the ribs, could be used for a simple plank type design. Use only minimal amounts of glue and sellotape to avoid obscuring the properties of the card.
Breakfast cereals have a wide range of ingredients. You probably choose yours because you like it - but what would you do if you wanted to improve your diet? How would you set about comparing breakfast cereals? In this activity you will do a survey of some cereals. You will use a computer spreadsheet to help you look at the results.

**What to do**
Collect your information about cereals. Make a note of the energy, protein, carbohydrate, sugars, fat, fibre and sodium per 100g of cereal.

You will now enter the information you collected into *Datalogging Insight*.

**Start the Datalogging Insight software**
- Select 'Modelling' from the 'Set-up' menu.
- Click on the *New* button.
- Close the Model window and open the Table window.

**Make your own Spreadsheet**
- Make a column to record the name of the cereal.
- Click the *New Column* button and add to the table a Value column with the name ‘Cereal’.
- Make a column to record the energy in the cereal.
- Click the *New Column* button and add to the table a ‘Value’ column with the name ‘Energy’.
- Make further columns to record the percentages of carbohydrate, protein, fat, fibre, sodium and sugar.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cereal</th>
<th>Energy</th>
<th>Carbohydrate</th>
<th>Sugar</th>
<th>Protein</th>
<th>Fat</th>
<th>Fibre</th>
<th>Sodium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>kJ</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>1</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

**Enter your results**
Click in the cell to enter your results.
Looking at Data

See the Skills Card for more details on using Datalogging Insight.

Find the highest and lowest
Find out which cereal has the highest sugar content:
- Click on the heading 'Sugar' to highlight the data in that column.
- Click on the Sort button.
- Choose descending order. Click OK.
1. Does this also have the highest energy content?
2. Which cereal has the lowest sugar content? Does this also have the lowest energy content?
3. Which cereal has the highest carbohydrate content? Does this also have the highest energy content?
4. Which cereal has the lowest carbohydrate content? Does this also have the lowest energy content?
5. Have you found any patterns in your data?

Find out if there are patterns in the data
One way to find patterns in the data is to draw a graph. For example you might want to test this idea:

Do cereals with the most sugar have the most energy?
- Click on the Graph button on the toolbar.
- RIGHT click on the vertical axis scale and select 'Energy' from the list of channels.
- RIGHT click on the horizontal axis scale and select 'Sugar' from the list of channels.
- On the Control Panel, click the data buttons to display 'Energy' only.
- Click on the Simple join button to connect the points.
- Adjust the axes scales or use 'Zoom' if necessary.
- Click the New Column button and add to the table a 'Formula' column with the name 'Total nutrients' and units '%' . Then use the Formula box to build the formula 'Total nutrients = Carbohydrate + Protein + Fat + Fibre + Sodium'.

Does the spread of results form a pattern?
Plot more graphs to answer these questions:
Do cereals with the most carbohydrate have the most energy?
Do cereals with the most fat have the most energy?
Do cereals with the most fibre have the least energy?
Summary of the ideas here

*Datalogging Insight* allows you to record your own data and uses features found in a spreadsheet. You can draw graphs, and change the items you want to plot very easily. In this way, students can search for patterns between different data sets - such as between the amount of energy and carbohydrate in a range of cereals.

Programme of study keywords

Balanced diets, collecting and analysing evidence, considering its strengths.

Data-logging skill level: beginner/medium

The activity uses the skills of making your own spreadsheet table, entering your data as well calculating and plotting it on a graph.

You will need

Cereal boxes or data or file on cereals

*Datalogging Insight* software, computer

Hints and tips

Most cereal packets display a standard list of nutritional contents of a 100g sample. These values conveniently correspond to the percentage composition.

The activity can be set in one of three ways:

1. Students gather their own data, build the table, enter the data and perform the analysis tasks.

2. Students gather their own data, open the data file 'cereals', enter their data and perform the analysis tasks.

3. Students open the data file 'cereals' and analyse the gathered data.
Scientists have collected a massive amount of data about the elements. When you set this information in a table you can start to compare the elements. When the table is on the computer you can find out even more about them.

**What to do**
Collect a ready made information file about the elements or create your own as described below.

**Start the Datalogging Insight software**
- Open the data file 'elements'.

**Looking at Data**
See the Skills Card for more details on using **Datalogging Insight**.

**Find the highest and lowest**
One way of quickly finding things out from a table is to sort it into order. You highlight the heading you want to sort by, and then click on the Sort button. For the first question here, you would sort the melting point heading:

<table>
<thead>
<tr>
<th>Atomic number</th>
<th>Element</th>
<th>Symbol</th>
<th>Atomic mass g/mol</th>
<th>Density kg/m$^3$</th>
<th>Melting point ºC</th>
<th>Boiling point ºC</th>
<th>Discovery year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hydrogen</td>
<td>H</td>
<td>1.01</td>
<td>0.09</td>
<td>14.0</td>
<td>20.4</td>
<td>1766</td>
</tr>
<tr>
<td>2</td>
<td>Helium</td>
<td>He</td>
<td>4.00</td>
<td>0.17</td>
<td>0.9</td>
<td>4.2</td>
<td>1895</td>
</tr>
</tbody>
</table>

Which element is most difficult to melt?
Which element has the highest density?
Which element was discovered most recently?
Were more elements discovered in this century or the last century?

Many years ago, Latin was an important language to chemists. Sort your elements by their discovery date. What can you say about the symbols for the elements discovered before the year 1400?

Which elements have a density greater than 5000 kg/m$^3$? Are they elements found anywhere special in the periodic table?

Which elements have boiling points of less than 25 ºC? Where are they found in the periodic table?

What physical state are they in? What else do they have in common?

Find when elements were discovered.
Sort the elements by their discovery year.
Which element was discovered most recently?
In which century were the most elements discovered?
Find out if there are patterns in the data
One way to find patterns in the data is to draw a graph. For example you might want to test this idea:

*Is there a connection between melting point and the atomic number?*

- Click on the Graph button on the toolbar.
- RIGHT click on the vertical axis scale and select 'Melting point' from the list of channels.
- RIGHT click on the horizontal axis scale and select 'Atomic number' from the list of channels.
- On the Control Panel, click the data buttons to display 'Melting point' only.
- Click on the Simple join button to connect the points.
- Adjust the axes scales or use 'Zoom' if necessary.

Look at your graph.

*Does the spread of points form a pattern? Describe this.*

Plot another graph to answer this question:

*Is there a connection between the atomic number of the element and its density?*
**Teacher’s notes**

**Summary of the ideas here**
*Data logging Insight* allows you to record your own data and use features found in a spreadsheet. You can sort the data to look at the information in a different way or you can draw graphs and search for patterns between different data sets.

**Programme of study keywords**
The Periodic Table. Handling data, drawing conclusions.

**Data-logging skill level: beginner/medium**
The activity uses the skills of sorting a table of data and plotting data on a graph.

**You will need**
Elements data file  
*Data logging Insight* software, computer.

**Hints and tips**
As a starter activity, students can be asked to simply look at the data table and answer fairly straightforward questions such as:

*Which element has the heaviest atoms?*

Students may also need familiarising with terms such as melting point, atomic number and so on.
Planets

Of the nine planets which revolve around the sun, some are large, some are small, some are close, some are far away etc. Many of their features have been measured at some time by scientists and recorded in tables.

Comparing some of those measurements can provide interesting information. Often, comparisons show patterns in the measurements which show up when we plot graphs. In this activity you will study measurements of the planets to find some of those patterns.

Start the Datalogging Insight software
- Open the data file 'planets'.

Looking at Data
See the Skills Card for more details on using Datalogging Insight.

Find the largest and the smallest
Use ‘Sort’ to rearrange the order of the rows to make it easy to see which planet is the largest and which is the smallest in diameter.
- Click on the top of the column to highlight the ‘Diameter’ heading.
- Click on the Sort button, then click OK.

<table>
<thead>
<tr>
<th>Item</th>
<th>Name</th>
<th>Temperature degC</th>
<th>Diameter Earth=1</th>
<th>Mass</th>
<th>Orbit time years</th>
<th>Distance million km</th>
<th>Gravity Earth=1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mercury</td>
<td>350</td>
<td>4.9</td>
<td>0.050</td>
<td>0.24</td>
<td>58</td>
<td>0.4</td>
</tr>
<tr>
<td>2</td>
<td>Venus</td>
<td>470</td>
<td>12.1</td>
<td>0.800</td>
<td>0.52</td>
<td>108</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Which planets are larger than the Earth? Which are smaller?
What is the range from smallest to largest?
How are the sizes spread over the range?
- Click on the Chart button to show the spread of values.

If you sort the rows according to mass instead of diameter, do you get the same order?
- Highlight the 'Mass' heading and click on Sort again. Try to explain the result.
- Use Sort to find out the:
  - hottest and coldest planet
  - longest and shortest orbit time
  - strongest and weakest gravity etc.
Find out if there are patterns in the data

One way to find patterns in the data is to draw a graph. For example you might want to test this idea:

Is there a connection between the time to orbit the sun and the distance of the planet from the sun?

- Click on the Graph button on the toolbar

On the Control Panel:
- RIGHT click on 'Orbit time' and select 'Left Y axis' and 'Auto scale'.
- RIGHT click on 'Distance' and select 'X axis' and 'Auto scale'.
- Click the data buttons to display 'Orbit time' only.
- Click on the Smooth join button to connect the points.

Does the spread of points form a pattern? Describe this.

Plot more graphs to answer these questions:

Is there a connection between the temperature on a planet and the distance from the sun?

Is there a connection between the gravity on a planet and the size of the planet?

Further Work

Kepler's law

Kepler found that he could predict the orbit time of a planet from its distance from the Sun. He did this using a calculation based on \((\text{Orbit time})^2\) and \((\text{Distance from the Sun})^3\). You can test out his idea as follows:

- Make columns to calculate the \((\text{Orbit time})^2\) and \((\text{Distance})^3\) for each planet.

Now plot a graph of \((\text{Orbit time})^2\) against \((\text{Distance})^3\) for each planet.

- Click on the Graph button on the toolbar.

On the Table headings:
- RIGHT click on 'Orbit' and select 'Left Y axis' and 'Auto scale'.
- RIGHT click on 'Distance' and select 'X axis' and 'Auto scale'.
- Click the data buttons on the Control Panel to display 'Orbit' only.
- Click on the Trial fit button and try to fit a straight line.

What conclusion can you draw about the connection between \((\text{Orbit time})^2\) against \((\text{Distance})^3\)?

This relationship is known as Kepler's Third law.
Summary of the ideas here
Datalogging Insight allows you to record your own data and uses features found in a spreadsheet. You can draw graphs and change the items you want to plot very easily. In this way, students can search for patterns between different data sets. The alternative, of manually plotting the data, is too laborious even to consider!

Programme of study keywords
The solar system, collecting and analysing evidence, drawing conclusions.

Data-logging skill level: beginner/medium
The activity uses the skills of making your own spreadsheet table, entering your data as well calculating and plotting it on a graph.

You will need
Set-up file on Planets
Datalogging Insight software, computer

Hints and tips
Students may need revision of terms such as ‘time for an orbit’, ‘length of a day’ and so on.
<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute temperature</td>
<td>50</td>
</tr>
<tr>
<td>Acceleration</td>
<td>80</td>
</tr>
<tr>
<td>Adaptation</td>
<td>27</td>
</tr>
<tr>
<td>Analogue sensor</td>
<td>5</td>
</tr>
<tr>
<td>Analysing aids</td>
<td>6, 8</td>
</tr>
<tr>
<td>Animals</td>
<td>24</td>
</tr>
<tr>
<td>Average</td>
<td>25, 81</td>
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<tr>
<td>Balanced diet</td>
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<td>Breathing</td>
<td>28</td>
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<td>Building bridges</td>
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<tr>
<td>Calculating aids</td>
<td>7, 8</td>
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<tr>
<td>Calibration</td>
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<tr>
<td>Caption</td>
<td>37</td>
</tr>
<tr>
<td>Cereals &amp; nutrition</td>
<td>87</td>
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<td>Change</td>
<td>21, 29</td>
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<tr>
<td>Change of state</td>
<td>19, 67</td>
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<tr>
<td>Chart</td>
<td>68, 72, 93</td>
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<td>Chemical reactions</td>
<td>56</td>
</tr>
<tr>
<td>Condition</td>
<td>61</td>
</tr>
<tr>
<td>Control</td>
<td>6, 64</td>
</tr>
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<td>Cooling</td>
<td>17, 64</td>
</tr>
<tr>
<td>Current &amp; voltage</td>
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<tr>
<td>Data-logger</td>
<td>5</td>
</tr>
<tr>
<td>Decay, radioactive</td>
<td>52</td>
</tr>
<tr>
<td>Digital sensor</td>
<td>5</td>
</tr>
<tr>
<td>Display format</td>
<td>6</td>
</tr>
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<td>Electrical Devices</td>
<td>47</td>
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<tr>
<td>Energy Transfer</td>
<td>23, 27</td>
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<td>Enzymes</td>
<td>36</td>
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<td>Evaporation</td>
<td>16, 67</td>
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<tr>
<td>Extrapolate</td>
<td>49</td>
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<td>Fabrics &amp; light</td>
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<td>Force</td>
<td>80, 86</td>
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<td>Formula</td>
<td>46, 50, 54, 62</td>
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<td>Free fall</td>
<td>76</td>
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<td>Gradient</td>
<td>38, 57</td>
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<td>Half life</td>
<td>54</td>
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<td>Handling data</td>
<td>7</td>
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<td>Interface</td>
<td>5</td>
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<tr>
<td>Interval</td>
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<td>Investigation</td>
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</tr>
<tr>
<td>Keyboard entry</td>
<td>7</td>
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<tr>
<td>Lungs</td>
<td>31</td>
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<tr>
<td>Measurement</td>
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<td>Nervous system</td>
<td>71</td>
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<td>Nutrition</td>
<td>87</td>
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<td>Ohm's Law</td>
<td>47</td>
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<tr>
<td>Overlay</td>
<td>61</td>
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<tr>
<td>Patterns in data</td>
<td>7</td>
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<tr>
<td>Pendulum</td>
<td>60</td>
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<tr>
<td>Periodic table</td>
<td>90</td>
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<tr>
<td>Photosynthesis</td>
<td>40</td>
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<tr>
<td>Planets</td>
<td>93</td>
</tr>
<tr>
<td>Pressure</td>
<td>48</td>
</tr>
<tr>
<td>Radiation</td>
<td>20</td>
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<tr>
<td>Radioactive decay</td>
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<td>Ratio</td>
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<tr>
<td>Reaction, enzyme</td>
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<tr>
<td>Reaction rate</td>
<td>56</td>
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<tr>
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<td>68</td>
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<tr>
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<td>29, 60</td>
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<tr>
<td>Skill level</td>
<td>11, 12</td>
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<td>Smooth</td>
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<td>Time measurement</td>
<td>68, 75, 79</td>
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<td>Triggered start</td>
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<td>Viewing aids</td>
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<tr>
<td>Voltage</td>
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